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Farm animal-waste management

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FARM ANIMAL-WASTE MANAGEMENT

Edited by J. Ronald Miner

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FOREWORD

This publication presents the current state of the technology and practice related to the management and disposal or utilization of animal wastes. The material includes the research results and collateral information assembled by researchers working in coordinated effort under regional project NC-69 (1963-1968) and subsequently under NCR-67 (1968-1970). A new regional program is currently active under project NC-93.

The material presented here and the continuing research in the North Central Region relates to a very extensive nationwide effort to develop waste-management systems to render livestock-production operations environmentally compatible with the public interest and to enhance production efficiency. The system parameters involved vary greatly according to geographic location and the nature and scale of enterprises. But the social, political, and economic pressures are general and increasingly intense throughout the U.S.

As is reflected in much of the technical content of this document, the agriculturally important North Central Region represents a wide range of operating parameters for livestock enterprises: from the industrial Great Lakes area to the outdoor-recreation-oriented north to the agriculturally heavy Great Plains; from densely populated northern Illinois to sparsely populated North Dakota; from humid northern Ohio to arid western Kansas; from the temperature range of northern Minnesota to that of southern Missouri; from the hills of southern Indiana to the plains of South Dakota; from confined dairy and poultry of Wisconsin to large, open waste management. The general objectives have demonstrated the desirability and productivity of regional coordination. At the same time, it has been essential that nearly all states participate to provide the input of specific systems design to provide compatibility with local circumstances. The various research approaches of participating stations appropriately reflect both the commonalities and the uniquenesses.

Both federal and state agencies are active in developing and implementing controls to enhance environmental quality. These efforts are obviously and logically focusing upon livestock enterprises along with many other environmental influences. Livestock producers are interested in conforming to the broad public interest, which includes both environmental quality and economical provision of livestock products. The development and application of new technology is essential to satisfy these conditions.

It is most important that research results be promptly related to needs for systems to fit local regulations and operating conditions in different states. At the same time, regulatory action must accommodate continued research and technological progress. And research accomplishment as reported herein and elsewhere must not provide satisfaction to preclude continued research effort toward more complete and effective solutions.

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Farm Animal-Waste Management

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ABSTRACT

Current practices, technology, knowledge, and research results are summarized as related to the management and disposal or use of farm animal wastes in the 13 states of the North Central Region and other cooperating states. Among alternative systems of management and treatments described, attention is given to relative effectiveness in eliminating or minimizing detrimental environmental and ecological consequences.

Detailed information is included on the biology and biochemistry of waste treatments; characteristics of animal wastes, including biological, physical, and chemical properties; aerobic, anaerobic, and combined treatments of animal wastes; composting, incineration, dehydration, and hydroponics; and actual and potential productive utilization of animal wastes. Needs for additional research are suggested.

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The livestock and poultry industry in the United States has achieved a very high level of efficiency in the production of meat, poultry, and animal products to feed the nation. The volume and efficiency of this industry must be expanded further if we are to feed our future population and to contribute to the alleviation of hunger and malnutrition on all continents. Research in nutrition has provided great advances in reducing the feed cost per unit of production and, along with research knowledge on providing the optimal environment for livestock and poultry, has given a healthy animal and a wholesome food product. Research in mechanization and materials handling, construction, and labor utilization also have helped reduce the cost per unit of production. Such research has been instrumental in creating the evolution from the days when a farmer fed a few pigs or cattle, milked a dozen cows, and raised a few chickens. Now, a feedlot may contain 100,000 beef animals, a dairy cooperative may milk 2,000 cows, a hog operation may include over 5,000 animals, or a poultry unit may handle 500,000 birds. Common by-products of all these operations are: (1) a pile of animal wastes and (2) wastes from the processing of animals into foods and by-products.

The problems of disposal of animal wastes have existed since the time that man first domesticated animals for meat, milk, eggs, and other products or as beasts of burden and even as pets. Animal manures, in some places, were utilized for such things as building materials or fuel or, as has been the experience in the United States, were randomly deposited on the land surface. Here, the decomposing manure served as plant nutrient and as organic humus to improve the soil. Current U.S. livestock-manure production, in excess of 1.7 billion tons a year, is a combination of the historical pasture or range production methods and the rapidly evolving practice of feeding animals in some degree of confinement. Several factors favor the confinement type of operation so that over 50% of the wastes from beef and dairy cattle, swine, poultry, and sheep is from feedlots and confinement rearing. This percentage will continue to increase. The factors favoring confinement production include: competition for land, better control of animal health and nutrition, production of a consistent high-grade product, requirements for less labor, more efficient use of water in water-short areas, and better adaptability to the development of the integrated operation. This type of concentrated husbandry, however, has seriously increased the problems of pollution control. The economic and handling advantages of chemical fertilizers over manure have added to the problem and have sharply decreased the demand for animal wastes.

The principal agents of pollution arising from animal manures are organic substances, both biodegradable and relatively unbiodegradable; inorganic substances, including plant nutrients; volatile substances, which may aesthetically degrade our air and water; agents infectious to man and animals and, possibly, to plants; and insects harbored by manure. The organic matter, upon reaching a body of receiving water, serves as substrate for aerobic-microorganism growth, which can rapidly deplete the available dissolved oxygen, or for anaerobic organisms, which produce a variety of noxious end products. When the oxygen uptake of the bacteria exceeds the reaeration capability of the receiving waters, the oxygen depletion disrupts the ecology of plant and animal life. Sport fish, sensitive to oxygen depletion, give way to poorerquality fish life, and eventually, if the oxygen level remains low, all fish life disappears. The body of water becomes anaerobic and "stinks."

The major inorganic elements in manure that serve as plant nutrients are nitrogen, phosphorous, and potassium. Quantities of other dissolved salts, particularly from urine, also are present and may be detrimental to the environment. The plant nutrients stimulate aquatic plant growth in surface waters, disrupt the ecology, and may rapidly lead to eutrophication, an aesthetically and economically undesirable situation for the farm or community. In some areas, the added salt load in the waterways could cross the threshold of salt toxicity. When inorganic substances reach the groundwater, they can degrade it, or lead to specific rural-health problems such as nitrate toxicity in man and animals.

The patterns of population growth in the United States, the increasing motor-vehicle travel, and the availability of time and money for recreational activity have, in many areas, resulted in housing, entertainment, business, and recreational developments close to lands previously devoted to livestock operations. Odorous substances from animal rearing are considered undesirable aesthetically, and the feeder or farmer is under strong pressures to eliminate or control them.

Livestock wastes also are a potential source of infectious agents of diseases that may affect animals and man by way of water and insects and, sometimes, by air. The list of such diseases is long, but examples are: brucellosis, coccidiosis, anthrax, leptospirosis, erysipelas, foot rot, histoplasmosis, hog cholera, salmonellosis, and encephalitis. Although waterborne disease that can be traced to animals is rare in humans in this country, sporadic cases and outbreaks do occur, and water-based recreation has created new opportunities for exposure.

Although many direct comparisons between the environmental degradation created by animal and human wastes have been made, no valid quantitative ratio can be generalized. Although most human waste is collected and processed by some treatment facility before discharge to a stream, animal manures, if treated at all, are processed within each operation. Most livestock manure is applied to cropland for nutritive values. Human wastes usually are handled in a closed system with a fairly uniform discharge rate to a stream. Population densities and distribution also are quite different between man and animals, as is the comparative potential of disease dissemination. It is obvious, however, that a steer discharges the waste equivalent of several humans.

The current interest of the people of the United States in environmental pollution has created demands upon the animal-producing industry to control water, air, and soil degradation by animal wastes. At the same time, the ever-increasing population is demanding even greater supplies of animal products. Reducing the quantity of waste produced is not possible. The current state of our technical knowledge can provide much help for the industry, but much research is still to be done. Along with further search for information and clarification of the "state of the art" described in subsequent sections, some new and unique ideas must evolve in animal feeding, housing, and management and in waste handling and treatment. More interdisciplinary work on the problem by engineers, animal scientists, economists, microbiologists, nutritionists, farm managers, etc., is badly needed.

BIOLOGY AND BIOCHEMISTRY OF WASTE TREATMENT

There is no such thing as waste organic material in the natural world. We call animal excreta waste and consider it offensive because it is not orderly in our sense of values. In the scheme of life, almost all the compounds that make up living bodies and compounds that come from their metabolism must be returned to a condition in which they may again be used to build, repair, or provide energy for other protoplasm. Without a system of reducing organic matter to a form in which the elements composing it may be used again, almost all life would shortly cease on this earth.

The microorganisms, with their system of extracellular and intracellular catalysts or enzymes, function in the scheme of life to reduce these materials, secure energy from them, or build new protoplasm. The biological reduction of these organic materials (waste) is predicated upon the synthesis of new (bacterial) protoplasm from it. These organisms, bacteria, fungi, actinomycetes, protozoa, bacteriophages, and algae, are all closely controlled in their action by the particular environmental requirements that physiological behavior requires.

We have long known that the cardinal principle on which all waste treatment is based is to provide an environment in which the microorganisms can bring about conversion of undesirable material to an inoffensive and stable state in the shortest possible time.

To bring about this desired condition it is necessary to consider (a) the waste we want to treat and (b) the organisms that we want to perform this chore for us. To bring about a reduction of a particular material by specific microorganisms necessitates the proper environment. The biochemical reactions of an anaerobic bacteria are quite different from an aerobe. The kind of oxygen, whether it be free or chemically combined, is important.

The excreta from each group of animals (swine, horses, sheep, cattle, milkcows, ducks, turkeys, and chickens) all have quite different characteristics of behavior with respect to the natural microbial flora and fauna. The presence or absence of bedding and the method of storage all influence the biological and biochemical changes that may occur.

The microorganisms involved in manure reduction are within the following groups: (a) bacteria (aerobic, anaerobic, microaerophilic, facultative, or obligate), (b) fungi, (c) actinomycete, (d) protozoa,

(e) algae, and (f) bacteriophage. Each organism finds its optimum environment under fairly restricted environmental conditions. For example, the presence of a very minute quantity of free oxygen will kill the important methane-forming bacterium *Sarcina methanica*. Some organisms are antagonistic and will not live in the presence of others, such as when one or the other organism produces an antibiotic. A synergism is a relationship in which some bacteria or molds form end products essential to other species. For example, *Proteus vulgaris* and *Staphylococcus aureus* each ferment lactose, producing acid, but no gas. If both species are inoculated into a tube of lactose broth, however, acid as well as gas is produced. There are many instances in which the synergistic action is important in industrial fermentations and microbial reductions of organic compounds.

The nature and condition of the waste material does much to select the types of microorganisms that predominate. Carbohydrates stimulate both the bacteria and fungi. Carbohydrates may be reduced through bacterial degradation to organic acids, aldehydes, ketones, and alcohols, which will stimulate the growth of Pseudomonas, Bacillus, Micrococcus, Achromobacter, and others of the soil flora. Proteus, Alcaligenes, and Flavobacterium are stimulated by the proteins. Inorganic solutions rich in nitrates stimulate a growth of algae, and abundance of algae and bacteria is favorable for the growth of the protozoa.

Water in an available form is essential for the growth of bacteria and protozoa. The density of dissolved organic and mineral material in water may be high enough to produce plasmolysis in many or all types of bacterial cells. This condition can and does occur in manure lagoons where the load of readily soluble materials is abundant and the volume of water is not sufficient to dilute the solution. In these instances, the manure is preserved against bacterial reduction. The density of the water in the solution must always be less than that in the protoplasm of the cell. Molds growing on the surface of the materials usually will thrive on situations too dry for bacteria or protozoa.

At pH 6.5-8.5, the bacteria will predominate over the fungi and yeasts. The fungi, in most instances, are favored by acid conditions, although one of the bacteria, *Thiobacillus thiooxidans*, finds an optimum reaction at pH 2.0-3.5. Certain of the Lactobacillii will form lactic-acid concentrations, lowering the pH to 5 or less, and prevent the growth of most of the bacteria that have an optimum of pH 6.5-8.5. This condition has been seen where the manure from dairy cows on a heavy-silage ration is collected in a lagoon.

The presence of free atmospheric oxygen plays an important role in the selection of bacteria in manure reduction. The feces as excreted are very low in dissolved oxygen. There is an abundant flora of *Escherichia coli*, a facultative anaerobe. Other bacteria abundant, but in smaller numbers, are Aerobacter, Lactobacillii, Streptococcus, and Micrococcus. The first reduction of the organic matter in solution is its incorporation in new bacterial protoplasm, with the by-product of carbon dioxide and water formed by the oxidation of the carbohydrates producing energy for the reaction. This stage of the biochemical changes results in no offensive odors and reduction of the readily oxidizable materials from the water. The critical element in this reaction is oxygen. The rate at which oxygen is used far exceeds the solubility of oxygen in water from the air. A deficiency of oxygen occurs in which the obligate aerobic bacteria are inhibited. The facultative anaerobic bacteria and obligate anaerobes secure their oxygen from the carbohydrates and proteins. The products of this reaction are limited by the abundance and kind of organism present. In most instances, there are sufficient nitrate-reducing bacteria present to produce enough ammonia to make the reaction somewhat basic, pH 7.4-7.8. *Escherichia coli* is the most abundant organism with this ability in early anaerobiosis.

The anaerobic degradation of the proteins is brought about by the facultative anaerobic and obligate anaerobic bacteria. The end products of their metabolism are skatol, mercaptans, butyric acids, the reduction of the sulfates to H_2S, and aldehydes. The presence of the methane-producing bacteria, Sarcina and Clostridium, reduces many of the volatile acids to methane.

Biochemical reactions occur at temperatures within a normal range of 0-60 C. Organisms with optimums 0-10 C are designated as psychrophilic; 10-40 C, mesophilic; and 40-60 C, thermophilic. There also is a group of important bacteria able to endure the temperature of 60 C and above for a time, but only able to grow at mesophilic temperatures; these organisms are designated as thermoduric bacteria. The temperature relation of microbial reactions is important. The enzymes responsible for both the intracellular and extracellular reactions with the organic materials follow, in general, the van't Hoff Rule of doubling the reaction for each 10 C increase in temperature up to the maximum. Temperatures beyond the maximum for a particular enzyme cause denaturation of the enzyme. Most chemical reactions that these organisms bring about, however, occur at a much lower temperature than would occur without the catalytic effect of the enzyme. These enzymes serve to initiate the reactions and also to control their speed in a way best suited to the particular organism.

In sanitary-engineering language, the manure lagoon is a primary processing unit; as such, it provides an illustration of the biological and chemical reactions found in the reduction of organic materials. Lagoons are pits excavated in a convenient location with respect to a livestock enterprise. The excreta from livestock are moved into the lagoon with water. The volume of water used is sufficient to cover the solids. This means that the dissolved materials, carbohydrates, and proteins are near saturation. The chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of 86,000 to 100,000 mg/l. in some lagoons demonstrate this condition. The bacteria present in this system come from the digestive tracts of the animals and from the soil. The organisms from the animals are the enteric bacteria common to warm-blooded creatures: Coliform, Aerobacter, Sarcina, Surratia, Pseudomonas, Micrococcus, Lactobacillus, Proteus, and in some instances, Clostridia. The soil organisms include, in addition to those in the excreta of animals, the Bacillii, Streptomyces, Achromobacter, Actinomycetes, the sulfur-reducing organism; Desulrovibrio, Thiobacillus, Beggeotoa, the denitrifying Clostridia, the Leptothrix, Crenothrix, and the methane-forming species of Sarcina.

The environment of the manure lagoon is strongly anaerobic. The demand for oxygen far exceeds the absorption from the atmosphere. Free oxygen is used immediately. The deamination of protein compounds reduces them to amino acids that are oxidized or absorbed into the cell of new protoplasm. The complex carbohydrate compounds, cellutose, starch, and other polysaccharides are hydrolized to available forms.

The biological stability of the manure is lower than the original material because of the reducing action of the microorganisms. The reduction of the compounds in the manure comes from the gases evolved. These are methane, ammonia, the volatile thio-alcohols (mercaptans), carbon dioxide, and the volatile sulfur compounds.

The anaerobic process of reduction is notable for the low heat value of the process. The low temperature of the manure lagoon, coupled with the high concentration of soluble materials, is a limiting factor in the success of the lagoon. The temperature of the lagoon liquids below the immediate surface is seldom above 18-20 C. The growth of bacterial cells and the action of the enzymes are very slow at low temperatures.

The other factor reducing the microbial action is the high concentration of dissolved materials in the liquid. Much of the time, the concentration exceeds that of the cell sap in the bacterium producing plasmolysis in the cell.

Much of the year, there is no odor from the manure lagoon because there is no action. The manure lagoon, in this instance, merely serves as a storage place for the excreta deposited.

CHARACTERISTICS OF ANIMAL WASTES

To devise systems for the management of farm animal wastes, a quantitative understanding of their nature and behavior is necessary. This understanding must include the bacteriological and chemical behavior of manure as well as the physical properties. An understanding of the biology and biochemistry of waste treatment is important to an understanding of waste-treatment systems.

Biological Properties

The biological characteristics of farm animal wastes are considered with respect to their degree of organic degradation or stabilization and their freedom from animal diseases transmissible to other animals and to man.

Desirable biological and microbiological characteristics of farm animal solid wastes are that they should be aesthetically free from objectionable odors, have the appearance of inert solids, and be free from animal diseases transmissable to man (zoonoses). When these farm animal wastes are applied to soil, they should not contaminate either air or water resources.

When the biological properties, including the microbiological properties, of the solid fecal wastes from farm animals are studied, it becomes evident that waste properties reflect the differences in feeds and in the digestive systems of ruminants and nonruminants as well as the complex interaction of microorganisms in the digestive systems of the animals. These factors regulate the proportion of organic matter in animal feces that is easily digestible and the proportion that is slowly degradable.

All farm animals utilize complex organic vegetation, as sources of energy and for the essential nutrients for growth and reproduction. The biological differences in the composition of the liquid and solid wastes among the farm animals can be best illustrated by comparing the nature of the feed and the digestive system of animals with only one simple stomach, such as swine, horses, and poultry, with the feed and digestive system for animals with a four-compartment stomach, such as cattle, sheep, and goats.

Nonruminant Digestion

Nonruminants, swine, horses, or poultry, require feeds high in readily digestible nutrients including carbon sources for energy, such as starches, sugars and fats, and nitrogen sources that include the essential amino acids, usually in the form of proteins. Similarly, the sulfur and phosphorus sources, vitamins, minerals, purines and pyrimidines, and other growth factors must be supplied in a form usable to the animal. Large amounts of roughage in the ration decrease the proportion of the food available for the animal. Since the animal lacks the enzymes necessary for cellulose breakdown in its digestive system, the cellulosic fibers appear in the feces as nondegradable roughage.

Microorganisms seem to have only a minor role in the digestive system of such animals. Few or no bacteria can be detected in the esophagus, stomach, or upper intestinal tract. Starch degradation starts with salivary amylases, is aided by acid in the stomach, and is completed in the intestine. The resulting blood glucose is used for an energy source. Fats furnish another energy source after they are emulsified with bile salts in the intestine. The nitrogen in the form of amino acids in proteins is made available by stomach pepsin, followed by proteolysis by enzymes secreted in the intestine. The extent of digestive action by the large numbers of bacteria that develop in the large intestine is not known. It is known that vitamin-synthesizing microorganisms in the intestine aid the host.

The kinds and numbers of microorganisms in the intestinal tract of such animals are almost unknown.

The anaerobic, non-spore-forming rods of the genus Bacteroides and related fusiform-shaped rods are reported to account for 50% of the microbial protoplasm in such feces. The presence of true bacteria, filamentous bacteria, fungi (such as yeasts and molds), viruses, and protozoa in feces has been reported, but the numbers and significance of these organisms are not known. Selected coliform bacteria and fecal streptococci, which have been studied as indicators of the presence of feces in the environment, will be discussed separately.

If an animal such as swine, with a single stomach, were provided with a balanced, liquid nutritional diet with all needed soluble sugars, amino acids, vitamins, growth factors, and minerals but no fiber or roughage, the excretion of waste uric acid in urine would be normal. The small bulk of feces, however, would consist entirely of waste body cells, secretions, and the intestinal microorganisms. The entire feces would be easily degradable in the absence of insoluble, fibrous organic matter. This illustrates the importance of the fibrous composition of feeds for swine, horses, and poultry. The horse is an example of a nonruminant that has a high percentage of roughage in its diet. The retention of the mass of vegetation in an enlarged caecum helps to complete the digestion of starches.

Ruminant Digestion

Ruminants, including cattle, sheep and goats, have four-compartmented stomachs so they can efficiently utilize the cellulose fibers, even though they, too, lack the enzymes necessary to liquify cellulose. Ruminants form a symbiotic partnership with microorganisms ingested with the feed by providing a first-stomach compartment, the paunch or rumen, which is simply a large fermentation vessel supplied with large amounts of saliva and a continuous supply of moist food. The constant 39 C temperature, the anaerobic environment, and continuous food supply results in the growth of enormous numbers of microorganisms, 10 billion per ml of fluid.

The cellulose fibers insoluble in water are rapidly solubilized by enzymes from ciliated protozoa and certain anaerobic bacteria with the formation of soluble carbohydrates. The carbohydrates, in turn, are rapidly converted to organic acids that form the energy supply of the animal. The anaerobic environment favors the fermentation of the sugars to the volatile organic acids by non-spore-forming anaerobic rods and cocci. Carbon dioxide gas is the product of fermentation by bacteria, such as *Bacteroides anylogenes* and *B. succinogenes.*

Other fermentations yield hydrogen or hydrogen donors used by the methane-forming bacteria, such as *Methanobacterium ruminantium*, to convert carbon dioxide, the most oxidized carbon form, to methane, the most reduced carbon form. The net result is the production of from 40 to 60 liters of carbon dioxide and methane gas per day in a rumen of 100 liters. These metabolic conversions of oxidized to reduced organic compounds occur among the carbon compounds, the sulfur amino acids and their derivatives, and the nitrogen compounds with the conversion of nitrates from plants to ammonia and then to amino acids and protein in the microorganisms.

The conversion of nitrate nitrogen, or even supplementary urea nitrogen, to ammonia and to the proteins of microorganisms is very important to a ruminant. For example, cattle feeding on alfalfa hay with 90% organic matter have only 10% digestible protein. Their deficiency in protein nitrogen is made up by the microbial protoplasm, which becomes available in the third and fourth stomachs where typical mammalian digestion begins. Vitamins and purines, pyrimidines, and even organic phosphorous compounds, such as nucleic acids, are also provided by the microorganisms.

The net result of the rumen digestion combined with the metabolic and synthetic action of microorganisms is to break down the fibrous celluloses and pentosans so that the amount of insoluble matter in the feed is much reduced in the feces. About one-fourth to one-third of the fecal organic matter is reported to consist of microorganisms.

The urine of mammals contains urea as a waste product, except that poultry excrete the nitrogen waste as uric acid in their feces. The action of many bacterial ureases releases ammonia and carbon dioxide from this waste urea.

Although the microorganisms of the intestinal content of ruminants have not been studied, a few selected types have been chosen as indicators of fecal pollution. These are the fecal coliform bacteria and the fecal streptococci. Although the total coliform bacteria occur in large numbers in the feces of all farm animals, the term is nonspecific since the ability to ferment lactose broth to form gas in 48 hours at 35 C is shared by about five genera of bacteria. The development of elevated temperature tests for true fecal *Escherichia coli* in E C medium at 45 C has been reviewed by Geldreich (3). The numbers and significance of the fecal streptococci also were discussed as possible indicators of fecal pollution. The numbers of fecal coliform bacteria and fecal streptococci also were reviewed by Geldreich as a possible method of distinguishing farm animal versus human fecal sources of water pollution as indicated by the Table 1 of coliform data from Geldreich and fecal streptococcus data from Kenner et al. (4).

A difference has been noted among the fecal streptococci in the feces of ruminants versus nonruminants. The term "fecal streptococcus" is a general term, which includes all the enterococcus group of streptococci as defined in Bergey's Manual (1) to include *Streptococcus faecalis, S. faecaliis* variety *liquefaciens,* variety *zymogenes,* and *S. durans*. In addition *Streptococcus bovis, S. equiinus,* and sometimes two species, *S. salivarius* and *S. mitis*, which originate in animal saliva, are all included in the term fecal streptococcus since they can be isolated from feces of cattle, sheep, and goats. Deibel (2) reviewed the properties of these streptococci. Since starch-degrading bacteria are important in the rumen, the number of starch-

Table 1. Estimated per-capita contribution of indicator microorganisms from some animals.

Animals	Av. wt. of feces/24 hr wet wt., g	Moisture %	Av. indicator density/gram of feces: Fecal coliform million	Fecal streptococci million	Av. contribution /capita/24 hr: Fecal coliform million	Fecal streptococci million	Ratio
Man.........	150	77	13.0	3.0	2,000	450	4.4
Duck.........	336	61	33.0	54.0	11,000	18,000	0.6
Sheep......	1,130	74	16.0	38.0	18,000	43,000	0.4
Chicken...	182	72	1.3	3.4	240	620	0.4
Cow.........	23,600	83	0.23	1.3	5,400	31,000	0.2
Turkey.....	448	62	0.29	2.8	130	1,300	0.1
Pig...........	2,700	67	3.3	84.0	8,900	230,000	0.4

Sources:

E.E. Geldreich. Sanitary significance of fecal coliforms in the environment. U.S. Dept. Interior, Fed. Water Pollut. Contr. Admin. Water Pollut. Cont. Res. Ser. WP-20-3. U.S. Gov. Print. Off. Washington, D.C. 1966.

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hydrolyzing streptococci has been observed to be from 1 to 20 million cells per ml of rumen fluid. The organism identified as *Streptococcus bovis* has been found in the feces of cattle, sheep, and swine. The presence of *S. bovis* in the feces of ruminants, but not in feces of other animals or man, may serve as an indicator of the presence of feces of ruminants in water or on land.

In studies on cattle manure, Witzel et al. (7) noted that the nitrogen was primarily in bacterial cells. The total bacteria by microscopic count ranged from 250 to 2,000 million cells per gram of wet weight of feces, yet aerobic plate counts demonstrated only 22 to 43 million cells per gram. Thus, only 2 to 9% of the total cells grew on aerobic plates. The remainder were either unable to grow under the methods used or were not viable. Coliform counts on Eosin-methylene-blue agar ranged from 340,000 to 560,000 cells per gram. Over 95% of these were typical *E. coli.* The "enterococcus" count on M-enterococcus agar was 3.5 to 17 million per gram. The acidic pH of the feces, pH 5.5-6.4, was probably the result of organic acid formation by these bacteria.

In summary, the biological composition of the feces from the various farm animals varies with the composition of the feed, whether the animal is a ruminant or nonruminant, and the types of microorganisms that interact with the feed in the digestive systems of each kind of animal. The animal feeder may find that studies on the entire system of feeding and waste disposal may result in improved operation.

Farm Animal Diseases Transmissible to Man

The second desirable characteristic of farm animal wastes is that they be free of animal diseases transmissible to other animals or to man (zoonoses). This review will include only the enteric diseases that can be expected to be transmitted through contaminated wastes, feces, and urine.

A wide range of pathogenic microorganisms are known to infect animals and man. These include as enteric pathogens, bacteria, rickettsia, mycoplasma, viruses, fungi (such as yeasts and molds), protozoa, and many kinds of worms.

Many excellent medical and veterinary textbooks are available for detailed reference on the transmission, pathogenesis, and diagnosis of the diseases; thus, many disease organisms will be listed without discussion.

The bacterial pathogens of animals and man would be a lengthy list if all possible suspected common pathogens were listed. It is surprising, however, to note the lack of information or documentation for many animal diseases where human illness has been possible but not confirmed. Many common human diseases, such as typhoid and paratyphoid fevers, that are enteric and waterborne are not proved to cause animal disease. The strains of *Excherichia coli* that cause extreme diarrhea in human infants, the "enteropathogenic E. coli," are different in serotype from many of the enteropathogenic strains isolated from young calves. Much additional study is needed to determine if this organism is zoonotic.

Among the true bacteria infecting farm animals and man are strains of Salmonella, Arizona, Listeria, Leptospira, Vibrio, Brucella, Mycobacterium, Coxiella, Chlamydia, and Mycoplasma. Salmonella infections are increasing in number of isolations, even though the human waterborne diseases are decreasing. The closely related *Arizona hersfeldii* also is isolated in increasing numbers in both animal and human illnesses.

Although over 1,200 serologically distinct serotypes of Salmonella are known, only 55 serotypes account for about 97% of those isolated from illnesses. The Salmonella species differ in outbreaks of farm animals and in man. The typhoid and paratyphoid fever strains infecting man have been rarely recovered from animals. The common pathogen for poultry, *S. pullorum*, is rare in other animals, and *S. gallinarum* has not been known to cause illness in other animals or man.

Other species of *Salmonella*, however, are very infective for both farm animals and man. Spino (6) has reported the *Salmonella* types by frequence of occurrence in man and in animals (Table 2).

Table 2. Frequency of occurrence of various salmonella types in man and animals.

Frequency[a]	Salmonella types: Animals	Man
1..........	S. typhimurium	S. typhimurium
2..........	S. heidelberg	S. derby
3..........	S. infantis	S. heidelberg
4..........	S. anatum	S. newport
5..........	S. montevideo	S. infantis
6..........	S. newport	S. enteriditis

[a]Arranged by decreasing frequency; 1 is most frequent.

Source: D.F. Spino. Elevated-temperature technique for the isolation of **salmonella** from streams. Appl. Microbiol. **14**:591-596. 1966.

Although the frequency of occurrence may vary, it is evident that many strains infect both farm animals and man. Miner et al. (5), in studies on a test feedlot, reported that *S. infantis* was present in storm runoff from the lot. The South Dakota laboratory reports that numerous isolates of *Salmonella typhimurium* have been obtained from the Big Sioux River.

Listeriosis, a liver necrosis caused by *Listeria* species, such as *L. monocytogenes,* infects cattle, sheep, swine, poultry, horses, and man. The disease may be transmitted by body excretions.

Leptospirosis, which causes jaundice in man, has been traced to cattle urine by the water route. Several species, including *L. pomona*, are involved.

Cholera is a disease of warm climates caused by *Vibrio comma*, which causes severe diarrhea of man. It is evidently an enteric-oral pathogen commonly transmitted by water.

Parrot fever, caused by *Chlamydia psittaci* in infected turkeys, may have a fecal route as well as the usual dust-inhalation route of infection for man. *Mycoplasma* infections of animals and man need more investigation to establish the extent of common infections by the enteric route. Of the enteric viruses, more than 30 enteroviruses are known. Some of these are poliomyelitis, Cocsakies, ECHO, bovine enteroviruses, swine enteroviruses, and avian enteroviruses. Infectious hepatitis may be transmitted to man by the fecal-water route.

Various fungi, both yeasts and filamentous forms, have been described as pathogens of farm animals and of man. Many of these are commonly transmitted by dust inhalation, yet they may be of fecal origin since many of the diseases are intestinal infections, including "thrush", caused by the yeast-like *Candida albicans*; cryptococcus, involving *Cryptococcus neoformans*; and also histoplasmosis, from *Histoplasma capsulatum.*

Protozoan infections resulting in severe diarrhea are caused by *Endamoeba histolytica* and related organisms. Other zoonotic dieases transmissible from animals to man range from trichinosis of pork to many worm infections. The purpose of this introduction is to suggest, rather than exhaustively review, the wide range of farm animal diseases transmissible to other animals or man by the enteric route. The ultimate disposal of farm animal wastes, feces and urine, must provide for sanitary disposal to prevent the perpetuation of such diseases to start new cycles of infection. The kinds and numbers of these disease agents in feces and urine are usually unknown, so much additional study will be needed.

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Physical and Chemical Properties

Environment and feed significantly affect both the defecation rate and quantities of manure produced by animals. During the last 10 years, significant changes have been made both in the palatability of feed fed to farm animals and in optimizing the environmental conditions for greater growth and production. Therefore, only data taken from work performed within the last 10 years were used in the development of Tables 3 and 4.

Table 3 shows references to the sources reviewed and the data extracted from them. Wherever there were more than one value from different sources for a parameter, the values were averaged in Table 3. These averages were used to develop suggested design figures for manure defecation rates per 1,000-lb. liveweight (Table 4).

Characteristics of Cattle-Feedlot Runoff

The trend toward large-scale cattle production continues in the North Central Region. Cattle feedlots with more than 1,000 head become more numerous each year. There also is a large number of cattle feeding operations in which 100-1,000 head of cattle are produced as a means of utilizing an individual farmer's corn production. This has resulted in many cattle feedlots having been built with a minimum of engineering design and with little consideration with respect to location, drainage, and pollution control. Some of these lots are located adjacent to streams, into which runoff may enter with little possibility of control or treatment.

Among the factors that influence runoff quality are the temperature, the moisture level of the feedlot surface before a storm, the rainfall intensity and duration, and the feedlot characteristics. Temperature is important because warmer temperatures produce higher organic-matter concentrations in the runoff. This may be due to the increased solu-

Table 3. Digest of recently published data on animal waste defecation per 1,000 lb. liveweight.

	Manure production	TS		VS		BOD production			BOD/COD	Fertilizer nutrients N	P2O5	K
Reference	lb./d	% w.b.	lb./d	% d.b.	lb./d	lb./d	lb. BOD/lb. TS	lb. BOD/lb. VS	%	% d.b.	% d.b.	% d.b.
Dairy cattle												
(1)	72	12.5	9.0	80[a]	7.2[a]	1.84	–	–	–	–	–	–
(3)	–	–	10.4	80.3	–	–	–	0.183	18.3	3.7	1.1	3.0
(5)	–	–	–	80[a]	–	–	0.102	0.129	8.2[a]	–	–	–
(6)	–	–	–	71.5[a]	–	–	0.278	0.388[a]	12.7[a]	2.8	1.04	0.34
b	105	9.0	9.4	–	–	–	–	–	–	–	–	–
(8)	–	–	–	–	–	–	–	0.232	–	–	–	–
(10)	–	–	6.8	85[a]	5.7	1.32	–	–	22.8[a]	5.5[a]	–	–
Average	88		9.0[c]	80.0[c]				0.233[c]	16.0[c]	4.0[c]	1.1[c]	1.7[c]
Beef cattle												
(6)	–	–	–	73.2[a]	–	–	0.195[a]	0.267[a]	13.3	12.5[a]	1.52	0.44
(10)	–	–	3.6	86.5[a]	–	1.02	–	–	31.3[a]	7.2[a]	–	–
(8)	–	–	–	–	–	–	–	0.236	–	–	–	–
Average				80.0[c]				0.252[c]		9.8[c]		
Poultry, hens												
(2)	64[a]	27.2	17.4[a]	70.3	12.2[a]	–	–	0.338	29.8[a]	23.3[a]	–	–
(3)	–	–	16.5[a]	77.5	12.8[a]	–	–	0.288	26.0	5.4	4.6	2.1
d	54	24.1	18.4	73.8	13.6	–	–	0.381	–	6.9	–	–
Average	59[c]		17.4[c]	74.0[c]				0.338[c]	28.0[c]	11.5[c]		
Swine												
e	52	10.5	5.5	81.3	4.5	3.1	0.57	0.696	38.3	3.35	–	–
(3)	–	–	–	78.5	6.3	–	–	0.320	26.7[a]	4.0	3.1	1.4
(4)	49[a]	–	–	–	–	–	–	–	36.2[a]	–	–	–
(5)	–	–	–	–	–	–	0.262	0.302	19.3	–	–	–
(7)	–	15.4	–	85.0	–	–	0.450[a]	0.382[a]	30.8[a]	5.9[a]	–	–
(8)	50	17.0	8.5	83.0	7.0	–	–	0.540	45.0	7.0	–	–
f	–	–	–	–	–	–	–	0.270	–	–	–	–
(9)	–	–	–	80.3	4.5	–	–	–	41.2[a]	–	1.9	1.4
Average	50[c]			82.0[c]	5.9[c]			0.363[c]	33.0[c]	5.6[c]	2.5[c]	1.4[c]
Sheep												
(5)	–	–	–	85.0[c]	–	–	0.074	0.087	6.2	–	–	–
b	37	–	8.4	–	–	–	–	–	–	–	–	–
f	–	–	–	79.0	–	–	0.104	0.116	–	–	–	–
Average	37[c]		8.4[c]	82.0[c]				0.101[c]				

Note: lb./d = pounds per day; w.b. = wet basis; d.b. = dry basis; d = day; TS = Total solids; VS = Volatile solids.

[a] Indicates value was calculated on the basis of data cited in the reference.
[b] W.B. Roller, Personal communication, Ohio Agr. Res. Center, Wooster. 1968.
[c] Indicates value used in the development of table 4.
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Table 4. Suggested values for manure defecation rates per 1,000 lb. liveweight in confinement animal production.

Items	Units	Dairy cattle	Beef cattle	Poultry, hens	Pigs	Sheep
Raw manure (WM)	lb./day	88	–	59	50	37
Total solids (TS)...	lb./day	9	–	17.4	7.2[a]	8.4
	% WM	10[a]	–	30[a]	14.4[a]	22.7[a]
Volatile solids (VS)...........	lb./day	7.2[a]	–	12.9[a]	5.9	6.9
	% TS	80	80	74	82	82
BOD........................	lb./day	1.7[a]	–	4.4[a]	2.1[a]	0.7[a]
	lb./day VS	0.233	0.252	0.338	0.363	0.101
BOD/COD..........	%	16	–	28	33	–
Nitrogen..............	% TS	4	9.8	11.5	5.6	–
P_2O_5..................	% TS	1.1	–	–	2.5	–
K........................	% TS	1.7	–	–	1.4	–

[a] Indicates value was calculated on the basis of data given in the references cited in table 3.

bility, or rate of solubility, of the manure pack in warmer water. Thus, more severe cattle-feedlot runoff incidents are likely to occur in the late spring and summer.

Research has indicated that the feedlot moisture level before a storm is important in determining the runoff characteristics. Dry manure surfaces are able to store from 0.6 to 1.0 inch of the initial rainfall. Wet manure packs hold a high concentration of dissolved organic matter at the onset of rainfall, and their surface storage capacity may be low. In extreme conditions, where areas in lots have a slurry consistency, much particulate matter is in condition for easy hydraulic transport. This effect of lot moisture on runoff quality suggests several design and management techniques to control runoff quality. Among these are proper slope for adequate drainage, proper site selection to allow rapid drying after wet periods, management to prevent the development of low areas that do not drain well, and adequate maintenance of waterers to prevent wet areas within the lot. This lot-moisture factor also has been directly related to periods of elevated odors arising from cattle feedlots. The bulk of cattle feedlot odors is related to manure decomposition, which can be controlled somewhat by maintaining a dry lot surface.

Rainfall intensity is related to runoff quality in that low-intensity rainfalls produce a higher concentration of organic matter and nitrogen in the runoff. This effect seems related to a longer contact time of the water with the manure during low-intensity rainfalls as compared with heavier rainfalls in which more of the water more quickly runs off the lot. From this, it becomes evident that perhaps the most severe condition of cattle feedlot runoff occurs when there is an extended period of low-intensity rainfall that, in effect, liquifies the manure pack, and then a sudden cloudburst forces the entire liquid mass into the stream. Rainfall intensity also is important in pollution damage because it influences the amount of runoff water from neighboring sites and, thereby, the amount of dilution in the receiving stream.

Design features of the cattle feedlot, such as surface material, slope, lot size, and frequency of manure removal, all have an effect on runoff characteristics. Little work has been done to evaluate these factors. Evaluation of the factors, based on existing data from various sites, is complicated by the interrelationship of these factors. For example, feedlot slope would tend to decrease runoff, organic-matter concentration by decreasing the amount of time water is in contact with the manure. The opposite effect occurs, however, because of the higher velocity of the water and a greater tendency to erode and actually scour particles from the lot surface. Early reports from research in Nebraska indicate little difference in runoff quality from lots with slopes of 3, 6 and 9%.[2] Researchers in Colorado found certain runoff quality parameters related to effective depth of overland flow.[3]

The first step currently used in pollution control from cattle feedlots is to divert any water not falling directly onto the lot around the facilities, thereby keeping this water free from manure. Although difficult in some existing lot situations, diversion of rainwater minimizes the amount of polluted runoff and makes it possible to collect feedlot runoff in a collection basin of reasonable size. Current pollution-control measures in conjunction with cattle feedlots include collecting runoff in some type of detention structure. Depending upon the various regulations of different states and other factors involved, 2 to 3 in. of runoff capacity generally have been specified as a minimum for these structures. Easily cleaned sludge-detention arrangements ahead of the main detention structures seem warranted. Broad, grassed waterways leading to the detention pool have been effective. Sludge settling basins with a detention time of 1 hour to 1 day are useful.

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[2] O.E. Cross. Private communication. University of Nebraska, Lincoln. 1969.

[3] S.M. Morrison. Private communication. Colorado State Univ. Ft. Collins. 1970.

Once collected in a detention structure, several possibilities exist for treatment or disposal of the runoff water. Among the methods that have been considered are controlled release (with or without treatment) to a watercourse, application to nearby cropland and as irrigation water, and evaporation and seepage. In much of the Midwest, evaporation rates do not sufficiently exceed average annual rainfall to allow use of evaporation for a long-term water disposal. Thus, some provision is necessary to remove collected runoff water.

A popular means of expressing the pollution potential of animal wastes for the benefit of the general public is to relate it to human population equivalents (PE). When making such comparisons for feedlot runoff, the base of comparison must be the unit of feedlot area rather than animal units. Accurate estimates are difficult to make with the data presently available.

To illustrate the general magnitude of the feedlot pollution problem, an estimate was based on data taken from small test feedlots in Kansas (1). The estimate started with the expected quantity of runoff for various sizes of storms. Then weather records were consulted to find the average number of storms in each size category that might be expected for the area. Since quality of feedlot runoff varied with the seasons, the information was combined to predict the amount of runoff per acre of feedlot during each quarter of a hypothetical "average" year. By relating this result to typical BOD concentrations in runoff for each period, an estimate was derived for total annual oxygen demand of runoff from an acre of feedlot. The computation showed that, in an area with an average annual rainfall of 30 in., it would require an estimated 2,500 lb. of oxygen to satisfy the oxygen demand of the annual runoff from an acre of concrete-surfaced lot and 1,200 lb. of oxygen for the runoff from a dirt lot.

If, for example, 62 lb. of oxygen are needed to satisfy the oxygen demand contributed by one person to domestic sewage in 1 year, the average annual oxygen demand contributed from a 1-acre concrete or dirt feedlot is equivalent to that of 40 or 20 people, respectively. If the runoff from a feedlot were discharged at a uniform rate each day of the year, it could be estimated that the discharge from a 50-acre dirt feedlot would be equivalent to the flow of untreated sewage from a community of 1,000 people. The stormwater flow from the feedlot, however, occurs on only 30 days of the hypothetical year. Thus, an average runoff event on one of these 30 days would carry, from each acre of dirt surface, an organic load equivalent to the untreated sewage from 250 people. The 10,000-head feedlot occupying 50 acres then is equivalent to a community of 12,500 people on that day. Storms obviously are never "average," so the contribution from any individual, protracted storm may be several times higher during those days when runoff is produced.

Tables 5 through 12 show ranges of values obtained in research in Kansas for BOD, nitrogen forms, suspended solids, and bacterial densities (1). The values should be taken as indicative only. They will undoubtedly be refined as the results of other research become available.

Salmonella have been isolated from both feedlot litter and runoff (2). From samples collected below a Kansas State University experimental feedlot (2), only a single strain, *Salmonella infantis*, was isolated, which indicated that all the cattle infected were infected by a single source. There is no way to know how many cattle in each lot were infected. No salmonellosis symptoms were exhibited by any animal in the test feedlots. The presence of pathogens in feedlot runoff may be important where receiving waters are used for recreation.

Research is continuing in the area of cattle-feedlot runoff control. Further characterization work is under way in many states. In Iowa, the various aspects of using lagoon or detention-pond water for application to cropland is being investigated. In the first year, 30 in. of water were applied to grassland from an anaerobic swine lagoon. As expected, the organic removal was nearly complete. In addition, nitrogen removal, by biological denitrification, took place in the upper few feet of the soil profile, eliminating approximately 70 to 80% of the nitrogen applied as ammonia. Initial results from work in Kansas with laboratory soil columns confirms that, with proper management, large amounts of nitrogen may be released from the soil profile through denitrification where large amounts of organic substrate are available. Further work must be done to substantiate this conclusion; with proper management and waste application, however, it seems feasible to dispose of cattle feedlot runoff by this technique. Also under investigation are various treatment schemes for feedlot runoff.

Table 5. BOD concentrations in runoff from a concrete experimental cattle feedlot in Kansas during various seasons of 1965.

Season	BOD concentration, mg/l.
Winter	
Typical	450
Range	300-600
Spring and fall	
Typical	900
Range	750-1,050
Summer	
Typical	1,300
Range	1,100-1,400

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 6. BOD concentrations in runoff from a dirt experimental cattle feedlot in Kansas during various seasons of 1965.

Season	BOD concentration, mg/l.
Winter	
Typical	250
Range	150-350
Spring and fall	
Typical	450
Range	350-550
Summer	
Typical	650
Range	550-750

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 7. Ammonia concentrations in runoff from a concrete and a dirt experimental cattle feedlot in Kansas.

Season	Concrete lot		Dirt lot	
	Ammonia concentration mg/l.	Ammonia N / Kjeldahl N	Ammonia concentration mg/l.	Ammonia N / Kjeldahl N
Summer	50-139	0.10-0.4	26-62	0.1-0.3
Fall	20-77	0.3-0.20	13-45	0.06-0.2
Winter	1.3-7.0	0.01-0.05	1.0-3.8	0.02-0.6

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 8. Nitrate nitrogen concentrations in runoff from a concrete and a dirt cattle feedlot in Kansas during two seasons of 1965.

Feedlot surface	Nitrate nitrogen concentrations, mg/l.	
	July-August	October-November
Concrete	1.0-6.0	1.0-5.0
Dirt	1.0-7.0	1.0-23

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 9. Nitrite nitrogen concentrations in runoff from a concrete and a dirt experimental cattle feedlot in Kansas during two seasons of 1965.

Feedlot surface	Nitrite nitrogen concentration, mg/l.	
	July-August	October-November
Concrete	0.1-11	0.4-2.3
Dirt	0.1-6.0	0.5-2.6

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 10. Suspended solids concentrations in runoff from a concrete and a dirt experimental cattle feedlot in Kansas in 1965.

Lot condition and rainfall intensity	Suspended solids, mg/l.	
	Concrete lot	Dirt lot
Warm weather (July-Aug.)		
Moist lot 1 in./hr	6,000	5,000
Dry lot 0.4 in./hr	3,000	1,500
Dry lot 2.5 in./hr	1,400	2,000
Wet lot 2.5 in./hr	3,000	3,000
Wet lot 0.3 in./hr	12,000	10,500
Cool weather (Oct.-Nov.)		
Wet lot 1.0 in./hr	2,000	1,800
Wet lot 0.5 in./hr	2,500	–

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 11. Densities of total coliform, fecal coliform, and fecal streptococcus bacteria in runoff from a concrete experimental cattle feedlot in Kansas during July through November 1965.

Bacteria counted	Millions of organisms per 100 ml, MPN[a]				
	No. values	Maximum	Minimum	Median	70% limits
Total coliform	47	790	3.3	130	33-348
Fecal coliform	49	790	3.3	130	35-240
Fecal streptococci	43	790	3.3	79	13-240

[a] MPN = most probable number.

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

Table 12. Densities of total coliform, fecal coliform, and fecal streptococcus bacteria in runoff from a dirt experimental cattle feedlot in Kansas during July through November 1965.

Bacteria counted	Millions of organisms per 100 ml, MPN[a] No. values	Maximum	Minimum	Median	70% limits
Total coliform	49	790	4.8	79	22-348
Fecal coliform	49	542	3.3	33	8-79
Fecal streptococci	49	542	4.0	24	8-79

[a] MPN = most probable number.

Source: J.R. Miner. Water pollution potential of cattle feedlot runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Mich.) 1967.

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Groundwater and Ammonia-in-Air Pollution of Cattle Feedlots

Two types of studies have been conducted that show the possible magnitude of groundwater pollution under cattle feedlots and the ammonia absorption by lake waters in the vicinity of large cattle feedlots.

In 1966, 129 cores from the surface to the water table were obtained in the South Platte Valley in Colorado, representing different kinds of land use varying from virgin grassland to old, heavily-used cattle feedlots (2, 3, 4). Cores were analyzed for nitrate, nitrite, ammonia, and redox potential. Water samples from beneath irrigated fields and feedlots were analyzed for these same variables and organic carbon and total and organic phosphorous. A summary of the average nitrate content of cores beneath the different kinds of land use and water-table samples when available is shown in Table 13.

Beneath feedlots, the amount of nitrate in 20 ft of profile ranged from none to over 5,000 lb./acre. The differences seemed related to feedlot management and the aeration status of the profile, but not to corral age. Beneath most feedlots, nitrate content decreased with depth, suggesting denitrification in the lower profile. There was an active population of denitrifiers beneath feedlots and high total bacterial count in the capillary fringe above the water table. Nitrate in the water tables for a given class of land use was highly variable so that no significant differences in the nitrate concentration of the water table beneath the different kinds of land use were observable. Water tables beneath

Table 13. Nitrate content of soil cores and water beneath various land-use patterns in Colorado.

Land use	Profiles 0-20 feet No. sampled	NO_3-N	Water table No. sampled	NO_3-N Mean	Range
		lb./acre		mg/l.	mg/l.
Virgin grassland	17	90	8	11.5	0.1-19
Dryland farming	21	261	4	7.4	5-9.5
Irrigated land (except alfalfa)	28	506	19	11.1	0-36
Irrigated land (alfalfa)	13	79	11	9.5	1-44
Feedlots	47	1,436	33	13.4	0.41

Source: B.A. Stewart, F.G. Viets, Jr., G.L. Hutchinson, and W.D. Kemper. Nitrate and other pollutants under fields and feedlots. Environ. Sci. Technol. 1:736-739. 1967.

feedlots had high concentrations of ammonium, soluble organic carbon and phosphorus compounds, and an offensive odor (urine).

Feedlots located on more sloping or less permeable sites than those in northeastern Colorado probably have less potential for contaminating groundwater by direct percolation. The movement of pollutants in groundwater away from feedlots has not been studied. Further information and data are contained in the references (1, 2, 3, 4, 5).

Laboratory-column studies have shown that from 25 to 90% of the nitrogen in cattle urine can be directly volatilized into the air as ammonia, the percentage depending on the water content of the soil and the rate of urine addition. About half the total nitrogen in cattle excrement is in the urine. To investigate the effect that such ammonia volatilization might have on eutrophication of lakes in the vicinity of feedlots, traps containing acid were installed at various distances from feedlots, and tanks of water were floated on rafts in lakes in northern Colorado in 1968 (1). Acid traps will collect about twice as much ammonia per unit of liquid surface as a water surface. Ammonia volatilization rates from feedlots seem highly variable, depending on surface moisture conditions, but are not restricted to any single season. A water body located over 10 miles from any large feedlot would absorb only about 3.5 lb. of nitrogen as ammonia per acre annually, but one located ¼ mile from an 80,000-head feedlot would absorb about 65 lb. A lake 35 feet deep located about a mile from this 80,000-head feedlot absorbs enough ammonia each year to raise its entire volume to a eutrophic level.

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AEROBIC TREATMENT OF ANIMAL WASTES

The Aerobic Process

The demand for a workable, low-odor-producing method of liquid-waste treatment has prompted widespread interest in the aerobic digestion process. Animal manure is a usable food source for many kinds of microorganisms. Aerobic bacteria require dissolved oxygen in the water for metabolism. The aerobes use the oxygen as a hydrogen acceptor, while the anaerobic bacteria use combined oxygen from sulfates, carbon dioxide, or organic compounds as their hydrogen acceptor. Facultative bacteria can use either dissolved oxygen or combined oxygen as their hydrogen acceptor.

In an aerobic process, with an unlimited food supply and a suitable environment, the mass of organisms increases with time at an exponential rate, and bacterial growth is limited only by ability to reproduce. During this time, the rate of oxygen consumption will increase, the food supply will be oxidized, and the mass of cells will increase. As the food supply or oxygen becomes limiting, the rate of cell production slows, with a corresponding decrease in oxygen consumption.

Endogenous metabolism, cell maintenance, exists at all times but becomes predominant when there is just enough food to keep the microorganisms alive. Under these conditions, the ammonia is converted to nitrates, the oxygen consumption rate levels off, and mineralization is increased due to the destruction of the volatile solids. The resulting accumulation of solids consists of fixed solids and unbiodegradable volatile solids (5). Figure 1 schematically diagrams the aerobic metabolism in a batch process.

A portion of the solids is relatively inert polysaccharide material, which accumulates at a rate of about 11% of the BOD removed in an activated sludge unit (16). Part of the organic matter in the sludge is inert to aerobic digestion, and inevitably accumulates along with fixed solids in the waste.

One of the most important parameters in the

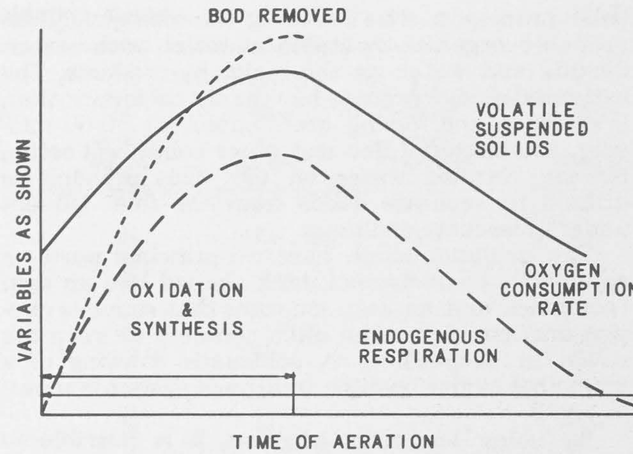

Figure 1. The Aerobic Metabolism Process

aerobic-treatment process is the food-to-organism ratio. This ratio, designated by the symbol F/M, is equal to the pounds of 5-day BOD applied daily per pound of volatile suspended solids contained in the treatment system (lb. BOD daily/lb. VSS) (17). Municipal oxidation-ditch systems usually have a low F/M ratio (about 0.05:1), compared with those in municipal activated-sludge, sewage-treatment plants (about 0.5:1).

A maintenance of from 1-2 mg/l. of dissolved oxygen (D.O.) in the waste liquid is sufficient to maintain aerobic conditions. The air as supplied in aerobic digestion is used both for agitation and for microorganism growth. Experiments with municipal waste have shown that the air requirements for oxidation are satisfied when sufficient air is supplied to keep the solids in suspension.

Nitrogen and phosphorus need to be present in the organic matter for bacterial growth. These two nutrients are needed in small amounts and usually are present in animal waste. The BOD/phosphorus required is about 100.

Various schemes, typically used for the treatment of domestic sewage, have been devised to utilize aerobic processes for the storage or treatment of livestock wastes. Among these are the oxidation ditch, aerated lagoon, and the naturally aerobic lagoon (oxidation pond).

Development of the Oxidation Ditch

The oxidation ditch was developed during the 1950's at the Research Institute for Public Health Engineering (TNO) in The Netherlands as a low-cost method for treating sewage emanating from small communities and industries (11,15). The first full-scale plant was installed at Voorschoten, The Netherlands, in 1954, is still in operation, and has been enlarged to handle increased populations. The oxidation ditch is a modified form of the activated-sludge process. Aerobic bacteria use the organic matter in the waste as food for their metabolic processes, thus reducing the biologically degradable organics to stable material, with carbon dioxide and water as the major by-products. The activated-sludge process has the characteristic that, if aeration and mixing are stopped for 30-60 minutes, the bacterial floc and other solids will settle, leaving clarified water on top. This principle is utilized to separate solids from the final effluent under quiescent conditions.

The oxidation ditch has two principal parts—a continuous open-channel ditch shaped like an oval race track and an aeration rotor that supplies oxygen and circulates the ditch contents to keep the solids in suspension. A schematic drawing of a municipal oxidation-ditch treatment system is shown in Fig. 2.

By using long-term aeration, it is possible to stabilize organic wastes to such an extent that solids can be dried without objectionable odors. The raw waste entering the ditch becomes diluted with the large amount of liquid present in the ditch. Two methods of discharging effluent from the oxidation ditch are batch and continuous flow. The liquid level in the batch type of operation is allowed to increase as manure is added to the ditch and is lowered periodically by removing all or a portion of the mixed liquor. In the continuous-flow method, the liquid level remains constant and is controlled by an overflow device. Many livestock producers favor the continuous-flow method in which the ditch contents overflow into a lagoon or holding tank.

Oxidation Ditches for Animal Wastes

The oxidation ditch is being used by livestock producers; about 400 ditches are now in operation across the country, primarily in swine operations (14). The oxidation ditch offers the following advantages over other possible treatment schemes: a) Being an aerobic process, it is odorless, with the exception of a slight ammonia or earthy smell. b) It has some ability to handle shock loads; once the biological process is operating properly, the ditch can absorb brief periods of heavy loadings. c) It requires little attention and maintenance. d) The process may be combined with the labor-saving, slotted-floor systems, requiring no extra

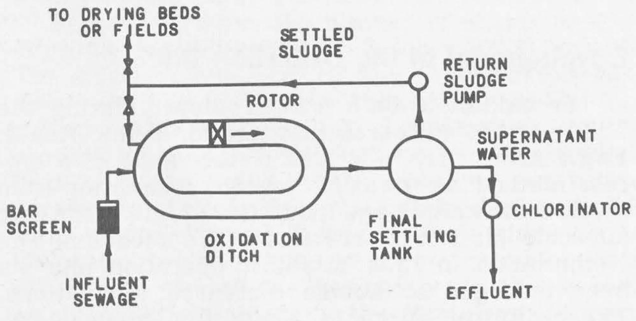

Figure 2. A schematic diagram of an oxidation ditch treatment plant for municipal wastes.

pumping or hydraulic system to move waste from the collection pit to the treatment plant.

Where an under-the-floor storage tank already is present, the only expenditure required for the channel is to round the corners and connect the ends of the gutter. Therefore, the main fixed cost is the rotor itself, approximately $250/ft of rotor in 6- to 8-ft nominal lengths (15). The major operating cost would be the power required to operate the rotors (usually 2- to 5-horsepower motors).

Design Criteria for Oxidation Ditches Under Slotted Floors

Livestock waste added to oxidation ditches usually is undiluted and does not contain significant wash water or bedding. Test results from four oxidation ditches for swine and two for beef cattle were used as a basis for the design criteria listed in Table 14. The ditch loading rates in Table 14 were computed on a basis of 30 ft^3 of liquid volume in the ditch per lb. of daily BOD added.

With these loading rates and starting with water in the ditch, operations could continue for an indefinite time if the suspended solids in the ditch were kept at about 25,000 to 30,000 mg/l. by periodic or continuous sludge removal.

Two requirements must be met when selecting a rotor for a specific livestock building: oxygenation capacity equal to twice the daily BOD added and a pumping capacity capable of moving the waste at a high enough velocity to keep the solids suspended, a minimum of 1 ft/sec. The rotor manufacturer should be able to supply a pumping value for his rotor, and McKinney and Bella (12) experimentally found a value of 3.4 ft^3/sec per ft of rotor (27½-in.-diameter cage rotor) at 100 rpm and 6 inches. They also found that, with 1.0 ft of liquid depth and 1.0 ft/sec liquid velocity, the channel width can be 1.2 ft per ft of rotor width.

To maintain adequate velocity in the ditch, the depth usually is limited to 18 inches and the channel length is limited to about 300 ft between rotors. Most rotor designs can transfer about 1.5 lb. oxygen hourly per ft of rotor in water at standard conditions at 100 rpm and 6-in. immersion (8). Rotor aerators have supplied much more oxygen than this under certain laboratory conditions (2), but higher capacities generally cannot be expected. The oxygen saturation value in waste water is always lower than the value in pure water. The aerator should be selected to supply an amount of oxygen equal to twice the BOD. When the power cost is 2 cents per KWH, the daily operating cost is approximately 2 cents per pound of BOD added if the rotor supplies 1.9 lb. oxygen per KWH.

Start-up procedure for the continuous effluent system is as follows:

a) Fill the ditch with the volume of water required by the ditch loading rate. Do not try to start with anaerobic liquid manure in the ditch.

b) Adjust the height of the rotor for the desired immersion depth (usually 4 to 6 inches). This should not require further adjustment for a con-

Table 14. Design recommendations for in-the-building oxidation ditches.

Animal unit	Weight lb./unit	Daily BOD lb./unit[a]	Daily req. oxygenation capacity lb./unit[b]	No. of animals /ft of rotor units/ft[c]	Ditch vol. ft3/unit[d]	Daily power reqmt. KWH/unit[e]	Daily cost cents/unit[f]
Swine							
Sow with litter	375	0.79	1.58	16	23.7	0.83	1.66
Growing pig	65	0.14	0.28	91	4.2	0.15	0.30
Finishing hog	150	0.32	0.62	41	9.6	0.33	0.66
Dairy cattle							
Dairy cow	1,300	2.21	4.42	6	66	2.33	4.66
Beef cattle							
Beef, feeder	900	1.35	2.70	10	40	1.42	2.84
Sheep							
Sheep, feeder	75	0.053	0.11	230	1.6	0.06	0.12
Poultry							
Laying hen	4.5	0.0198	0.0396	650	0.6	0.021	0.042

[a]From table 4. Use specific production data when known.
[b]Twice the daily BOD.
[c]Based on 25.5 lb. of O_2 per ft of rotor per day.
[d]Based on 30 ft^3 per lb. of daily BOD.
[e]Based on 1.9 lb. of O_2 per KWH.
[f]Based on electricity at 2 cents per KWH.

Source: D.D. Jones, A.C. Dale and D.L. Day. Aerobic treatment of livestock wastes. Ill. Agr. Exp. Sta. Bul. 737. 55 pp. May 1970.

tinuous-effluent system because the liquid depth will remain constant.

c) Put animals into the building and start the rotor. It is best to put the animals in gradually if possible so that the full load will not be applied until the bio-oxidation system becomes established.

d) Monitor the ditch for foam. Some foaming is likely at start-up. It may be controlled with anti-foaming agents if the condition exists; even a quart of engine oil applied a time or two during the foaming period will suffice.

Keep the rotor running and do not upset the bio-oxidation system by sudden excessive changes in the loading rate; i.e., suddenly adding or removing large numbers of animals or spilling large amounts of animal feed into the ditch. After a few months of operation, it may be necessary to remove sludge from the system even though the effluent removes solids continuously in the mixed liquor overflow. An easy way to accomplish this is to dilute the liquid by putting a water hose into the ditch and allowing water to run for several hours.

Operating Problems

All waste-treatment plants require some operator attention. Each system must have regular maintenance to function properly over an extended period. The oxidation ditch is, however, relatively simple and easy to maintain. The most critical period of operation is start-up.

If adequate oxygen is not maintained in the ditch, anaerobic bacteria will develop and produce odorous end products. The operator can smell when the ditch is operating properly since aerobic ditch waste is odorless. The anaerobic end products are surface active so that foaming usually accompanies odor. Although foam can be controlled with anti-foaming agents, the anaerobic problem is best controlled by adding more oxygen to the ditch contents. If the mechanical system cannot supply the needed oxygen, it may be done temporarily by adding a chemical such as ammonium nitrate or sodium nitrate (12).

Settled solids can be a nuisance to ditch operation. Not only do they reduce the effective ditch volume, but they also will undergo anaerobic decomposition and create foaming problems. Care should be taken in the hydraulic design of the system to prevent solids accumulation in the bottom of the ditch.

McKinney and Bella (12) state that "at no time has foaming ever been noticed except at start-up and with anaerobic conditions." In a system that seemed aerobic, but was foaming significantly, solids were settling out in the corners just before the rotor. These solids underwent anaerobic decomposition and released their surface-active metabolic end products to the water. Adequate oxygen prevented odors, but the material reached the rotor before it could be metabolized, and foaming resulted. Removal of the settled solids eliminated the problem.

Foaming, except during the start-up, may be the best indicator of trouble somewhere in the system. Not only is foaming an indication that the ditch is not treating the waste properly, but the foam may rise up through the slats and endanger penned animals by suffocation.

Some ammonia is often given off as urine drops into the ditch. In a properly operating ditch, the bacteria will convert most of the ammonia to nitrates. If oxygen is insufficient in the waste water, the ammonia may be liberated into the atmosphere. A slight odor of ammonia will always be present in a building because of urine splashing against the slats, but a strong ammonia odor may be a sign of insufficient oxygen in the ditch.

Oxidation ditches are simple in construction and operation. The major operating problem is failure of rotor bearings. It is essential that the unit be easy to remove to replace the bearings. Another problem can be in the drive between the motor and the rotor. Gear reducers can assist in speed reduction, but their cost is high, and their efficiency low (12). Efforts have been made to establish direct drives with belts. These have worked well, but require low-speed motors to gear the speed down to 100 rpm at the motor. Belt drives have worked better for rotors than have chain drives. The two major manufacturers of livestock oxidation-ditch rotors concur and have replaced all chain drives with belt drives. Belt drives tend to absorb the shock of blade contact with the water better than do chain drives. It seems that the belts slip slightly with each impact, with a net result of less wear on the equipment.

If problems from high humidity are anticipated and if climate and ditch construction permit, it may be advisable to place the rotor outside the building. Research to date concerning evaporation in the building is definitely lacking. The effect of a severe winter climate on an exposed rotor, however, will likely outweigh whatever evaporation problems are anticipated.

Effect of Cold Climate

Ice formation in the ditch has been reported in Minnesota and Illinois in beef operations. Moore, Larson, and Allred (13) state, however, that their studies in Minnesota indicate that the oxidation-ditch system can be used to treat beef-cattle waste in climates with extended periods of subfreezing temperatures. Foam production occurred on several occasions in cold weather, but did not force shutting down the rotor. In one trial in November, December, and January, the monthly average liquid temperature was 36.8 F. An ice layer up to 1 inch thick formed over part of the ditch. In one reach of the ditch, the foam froze and provided an insulation blanket. The liquid velocity of 1.2 to 2 ft/sec probably minimized the icing problems.

In a beef-cattle unit at the University of Illinois, up to 2 inches of ice has been observed in the channel opposite the rotor when the temperature dipped to 5-10 F. for a week (9). The velocities in this ditch, although not known exactly, were not as great as the Minnesota study. The insulation properties of foam that Moore, Larson, and Allred (13) reported also were observed in two sections of the ditch in the Illinois study.

Biological activity in the ditch is influenced by cold climates. Dale *et al.* (4) reported that temperature had a significant effect in their laboratory studies (Table 15). The aerobic decomposition process works nearly twice as well at 24 C as at 4 C. The values in the table are for 12- to 15-day studies.

An oxidation ditch can continue to operate through cold weather. During cold weather, however, bacterial activity and, therefore, oxygen requirements are reduced, and a shutdown period is possible. Exhaust fans drawing air from under the slats should allow the heat produced by the livestock to help prevent the oxidation ditch from freezing.

Special precautions must be taken when starting a ditch in cold weather. The temperature of the liquid should be well above freezing and as warm as possible. Some type of heater may be needed in the building near the ditch for the first few weeks until a large bacterial population is developed.

Aerobic Lagoons

The use of aerobic lagoons, either as a final disposal site or as an intermediate treatment before some other disposal method, has a place in the livestock industry. Aerobic lagoons are classified by the method of aeration: a) natural and b) mechanical. Since both are aerobic, they will not produce highly odorous gases. This assumption is based on the premise that sufficient oxygen will be supplied to the system to insure the maintenance of an aerobic condition.

Naturally Aerated Lagoons

The naturally aerated lagoon (oxidation pond) is a shallow basin 3 to 5 ft deep for treating sewage or other waste water by storage under climatic conditions that promote the introduction

Table 15. Average reductions of volatile solids, COD, and Kjeldahl nitrogen in 12- to 15-day laboratory aeration studies conducted at two temperatures.

Criteria	Temperature 24 C	4 C
Volatile solids reduction	42.3%	20.1%
COD reduction (dichromate)	53.6%	24.5%
Kjeldahl nitrogen reduction	43.5%	15.9%

Source: A.C. Dale, J.R. Ogilvie, A.C. Chang, M.P. Douglas, and J.A. Lindley. Disposal of dairy cattle wastes by aerated lagoons and irrigation. pp. 150-159. In: Proc., Animal Waste Management. Cornell Univ. Conf. on Agricultural Waste Management. 1969.

of atmospheric oxygen and that favor the growth of algae; namely, warmth, light, and wind. Bacterial decomposition of the wastes releases carbon dioxide, which promotes heavy growths of algae. Ammonia and other plant-growth substances are used by the algae, and dissolved oxygen is kept at a high level. The driving force in this type of self-purification is photosynthesis supported by a symbiosis between saprophytic bacteria and algae.

If oxidation ponds are properly designed and constructed, a good destruction of coliform organisms and a reduction of BOD occur. The effluent usually is high in dissolved oxygen, often supersaturated during the day. Loadings in the vicinity of 45 lb. of BOD per acre generally are acceptable in the Midwest (17). Oxidation ponds may require solids removal after several years, and weeds should always be kept under control to prevent mosquito breeding and other nuisances.

For livestock waste treatment, some modifications have been made in the recommended loading rates. Clark (3) in 1965 suggested that an acre of aerobic lagoon would handle the wastes from 275 to 300 head of 150-lb. feeder pigs. This is a loading rate of about 96 to 105 lb. of BOD daily per acre. With a lagoon 5 ft deep, there is an average of slightly less than 750 ft^3 per hog or about 5 ft^3 of capacity per pound of swine. The present recommendation of the Midwest Plan Service (1), however, is 2 ft^3 per pound of swine for an anaerobic lagoon, with no particular limits on the depth. In much of the Midwest, particularly colder areas, Clark's (3) early recommendations likely would not provide an aerobic system if the lagoon receives all the waste.

Table 16 gives recommended sizes for naturally aerobic lagoons for livestock. The size can be reduced by removing the settleable solids by using a settling basin or septic tank. It is estimated that up to half the BOD might be removed by this method, which would reduce the size of the lagoon or permit it to handle the waste from more livestock.

In addition to the large surface area required, oxidation ponds also require the availability of a rather large water supply. The large surface area promotes extensive evaporation, and unless well sealed, seepage can contribute to water-balance problems. Because of these reasons, oxidation ponds have not found favor with livestock producers. Their use has been limited essentially to receiving effluent from anaerobic lagoons. In this application, they have further treated the wastes. Some producers have used oxidation ponds to store anaerobic lagoon effluent for eventual disposal by land application.

Table 16. Suggested surface area for naturally aerobic lagoons[a] used for the treatment of livestock wastes.

Livestock	Surface area per pound of animal ft^2
Poultry............	4.5
Swine.............	2.5
Dairy cattle.....	1.5
Beef cattle......	1.5

[a]Maximum depth 6 ft, 3 to 4 ft preferred.

Mechanically Aerated Lagoons

In mechanically aerated lagoons, oxygen is furnished by some mechanism that "beats" or blows air into the water with a portion of the oxygen being dissolved. The lagoon, therefore, is not dependent on natural aeration, the wind or algae growth, for the oxygen supply. Thus, the design criteria (surface dimensions and depth) differ greatly from those of the oxidation pond or naturally aerobic lagoon.

Satisfactory aerobic treatment of livestock wastes has been obtained in mechanically aerated lagoons that have a volume approximately 50 times the daily manure production (Table 17). If the aerated lagoon is for final treatment or long-term storage of the waste, however, a larger size usually is needed. If one intends to remove sludge from a lagoon yearly or more often, the size may be reduced.

The depth of the mechanically aerated lagoon should be much greater than for an oxidation pond. Depths of 15 to 20 ft. may be used satisfactorily, thus reducing the surface area required for any given volume.

For continuous operation, a mechanical aerator that will provide an oxygenation capacity of 1.5 times the total daily BOD loading is the minimum size recommended. If the operation is to be intermittent (off in the extremely cold months, such as December, January, and February), the aerator should have an oxygenation capacity of at least twice the daily BOD loading.

For odor control, the aeration (oxygen) requirements are approximately those for stabilization. But for partial odor control, a lesser oxygen supply of one-third to half the daily BOD may be beneficial. A low rate of aeration reduces the release of many volatile acids and the accompanying gases. Generally, ammonia production is not stopped, and the odor is still detectable. Although it is not clearly understood, the pH is raised, with the low aeration rate preventing the release of H_2S. But ammonia release will be increased.

Table 17. Suggested water volume of a mechanically aerated lagoon for long-term detention.

Livestock	Volume per pound of livestock ft^3
Poultry............	0.75
Swine.............	1.00
Dairy cattle.....	1.25
Beef cattle......	0.75

There are numerous methods for aerating lagoons. Floating aerators seem satisfactory, but other schemes, such as compressed air entering through diffusers (perforated pipes), also work. Some manufacturers of floating aerators guarantee an oxygenation capacity of about 3.2 lb. per horsepower-hour at a standard condition of 20 C in clean water at a given percentage saturation of dissolved oxygen in the water.

General Considerations

With an aerated-lagoon system for the treatment of livestock wastes, consideration must be given to the entire system. Some means of routine flushing of the wastes into the lagoon must be provided. In most installations, daily flushing is mandatory, and more-frequent automatic flushing may be required to prevent odor production from shock loads. Arrangements may be made to use water from the lagoon for channel or floor flushing when other adequate water supplies are not available. Drainage from the collection channels to the lagoon should be by gravity if at all possible. If this is not possible, all channels and floors should be drained to a centrally located sump with an automatically activated pump.

The actual layout of the lagoon is variable and depends in part on the available area. A round or oblong shape, depending on the number of aerators to be used, would be the most desirable for waste distribution. The lagoon should be located near the livestock area to limit piping maintenance and problems of stoppages.

Another factor that should be considered in the location of the lagoon is the soil characteristics. The lagoon should be located in a tight, preferably clay, soil to prevent leakage and subsurface-water contamination. If such a soil is not available, arrangements should be made to waterproof the lagoon sidewalls and bottom. Sodium carbonate mixed with clay soil has been found a good waterproofing mix, as has bentonite clay and other commercial materials. The use of soil cement or the installation of a plastic lining are also accepted practices in sealing lagoons.

Loading the lagoon is a critical factor in the maintenance of proper operation. Unusually large loads (slugs) of waste materials change the pH and other environmental characteristics, deplete the oxygen, and often result in what is called a "shock load." The biological-digestion process is upset, and the lagoon does not function as it should. The most desirable loading system feeds the lagoon (bacteria) with a steady, continuous feed in such quantity as to balance the feed, the microflora, and the oxygenation capacity. Loading twice daily is satisfactory, but more frequent loading is desirable.

The mechanically aerated lagoon should be aerated continuously since aerobic conditions exist only when oxygen is freely available. When oxygen is not available, the growth and reproduction of aerobic bacteria are inhibited, and anaerobic conditions develop. If this condition persists, the whole system is "upset," and considerable time is required to return to the normal aerobic condition once the aerator is restarted. Part of this problem occurs because storage of dissolved oxygen in the water is impossible; the oxygen saturation range is only about 6 to 9 mg of oxygen per liter of water. After saturation, additional oxygen is not held by the solution, and further aeration is of little use and would add unnecessary expense. The ideal system then is one in which oxygen is being supplied at a rate that will satisfy the oxygen demand.

Cold Weather Aeration

The rate of bacterial decomposition is slowed as the temperature decreases. Below 40 F, bacterial action is greatly reduced, and below 35 F, there is little activity. On this basis, it seems that little decomposition is accomplished by operating aerators in extremely cold weather. The aerator should be started as soon as the temperature begins to warm in the spring, however, so that aerobic bacterial action can be re-established. Some objectionable odors can be expected during the startup period.

A 2-horsepower floating aerator operating in a 6-ft deep lagoon at the Purdue University Dairy Farm did not freeze up during the winter of 1967-68 (4), but there was little evidence of bacterial activity during that period. Ice piled up around the aerator, and its efficiency was probably impaired. A similar situation was observed at the University of Illinois during the 1968-69 winter (6).

Removal of Sludge and Surplus Water

Considerable decomposition of organic solids occurs in aerobic lagoons. Although the rate of decomposition is greatly reduced after some 30 days, decomposition does continue, and it is believed that, in a period of 1-½ to 2 years, the volatile solids may be reduced as much as 60- to 70%.

Even with good degradation, however, solids (sludge) eventually will accumulate in the lagoon until removal is necessary. The rate of sludge buildup depends upon the size of the lagoon in relation to the manure added and the breakdown that occurs. The sludge will contain considerable nutrients and may be removed and applied directly on cropland if available. Otherwise, it may be discharged onto a sand or gravel bed for dewatering and drying. Late fall seems a good time for removal of sludge from lagoons. The solids are the most stabilized at that time, and the odors are low if the lagoon has been well aerated during the previous 7 to 8 months. A vacuum pump or other sewage pump will remove sludge from the bottom of a lagoon. If the sludge has compacted, an auger may be used for stirring and mixing.

When excess water must be disposed of from a mechanically aerated lagoon, irrigation with the mixed liquor seems desirable. Sludge buildup is not a problem since suspended solids are removed by the irrigating unit. Essentially all criteria for operation of the naturally aerated lagoon apply to a mechanically aerated lagoon. For example, the loading rates, temperature effects, and the need for continuous operation are no different. The main difference is the desludging, which is accomplished by the irrigation system. As a check on this system, an experiment (4) was performed by researchers at Purdue University. A similar study (10), using anaerobic lagoon effluent, was conducted at Iowa State University.

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ANAEROBIC TREATMENT OF ANIMAL WASTES

Anaerobic processes are those that take place in an environment devoid of molecular oxygen. In an environment where oxygen from the atmosphere is not available for the final energy-producing metabolic step, some other alternative must be utilized. Chemically bound oxygen is commonly used for energy production in these processes. The oxygen may be bound with sulfur in sulfate ions, with nitrogen in nitrate ions, with carbon and hydrogen in various organic compounds, or with carbon alone in carbon dioxide. Among anaerobic systems currently important in waste treatment are the septic tank, the anaerobic digester, and the anaerobic lagoon.

The basic attraction of the anaerobic process is its ability to decompose more organic matter per unit volume than an aerobic counterpart. For this reason alone, the anaerobic process deserves consideration for the initial stabilization of strong organic wastes.

A characteristic of anaerobic digestion is the production of methane as a principal end product. Depending upon the exact nature of the raw wastes and digestion conditions, the gas produced can be 60 to 80% methane. This gas may be captured for use as heat, electrical, or mechanical energy, depending upon the need. The remainder of the gas is carbon dioxide, with small quantities of various intermediate products, including hydrogen sulfide and methane. It is this last group, less than 1% of the gas produced, that is responsible for most of the toxicity and odor problems that historically have limited the use of anaerobic digestion.

Other uses and applications of the anaerobic-treatment processes may be as important as organic disposal and methane production. Among these uses are:

1. **Improved dewatering characteristics.** Undigested organic sludges retain water with great tenacity.

Well-digested sludge drains and dries quickly; undigested or poorly digested sludge does not drain well and must depend upon surface evaporation and diffusion for drying.

2. **Reduction of solids volume.** Depending upon the nature of the waste constituents, organic solids may be liquified by 40 to nearly 100%. Carbohydrates are converted completely to methane and water, while certain woody materials are reduced only 50% or less. No reduction in inorganic solids may be expected in anaerobic digestion. Conventional sludge digestion in municipal waste-treatment schemes produces a 50% reduction in organic (volatile suspended) solids.

3. **Odor reduction.** Well-digested anaerobic sludge has a musty odor generally less offensive than that of raw organic wastes. It dries rapidly and does not support further anaerobic decomposition. Thus, digested solids may be field-spread in areas where odor complaints would prevent the spread of fresh manure. Coupled with the reduction in odor potential is the reduction in fly problems associated with the disposal of digested solids. Digested solids are less attractive to flies, both because of the lowered putrescible organic-matter content and the increased dewatering speed.

4. **Pretreatment ahead of aerobic systems.** The high volumetric organic removal rate of anaerobic processes makes them particularly suitable as the first step in a combined anaerobic-aerobic system. Combined systems offer a high degree of treatment in a more economical manner than does the exclusive use of an aerobic system. Systems of this type have found several applications in the meat-packaging industry and have been explored to a limited extent for animal waste treatment.

The Anaerobic Process

The anaerobic decomposition of wastes is the result of anaerobic and facultative bacteria. The environment is not suitable for the growth of either algae or higher animals. Aerobic bacteria are excluded by the absence of dissolved oxygen.

Acid-Forming Phase

Microorganisms hydrolyze organic matter and metabolize the products to organic acids, alcohols, sulfides, amines, and carbon dioxide. No single group of bacteria is able to degrade the variety of raw materials present in animal wastes; therefore, a heterogeneous population is present. The composition of the microbial population is a function of both the material present and prevailing environmental conditions. This phase involves a liquification of insoluble substances by the action of specific enzymes that allow the further metabolism of these materials.

Cellulose, hemicelluloses, pectins, lipids, and proteins are the more common classes of materials partly decomposed by enzyme activity. Lignins are largely unchanged in anaerobic decomposition. The hydrogen acceptors for the initial breakdown of complex organics are nitrate and sulfate ions as well as combined oxygen existing in organic compounds. Typical reactions during this phase include:

$$\text{Organic matter} + \text{sulfate reducing bacteria} + SO_4 \rightarrow \text{more bacteria} + \text{organic intermediates} + H_2S + CO_2 + H_2O + \text{energy}$$

$$\text{Organic matter} + \text{facultative bacteria} \longrightarrow \text{more bacteria} + \text{organic intermediates} + CO_2 + \text{energy}$$

Intermediate breakdown products during this phase of digestion include various hexoses, such as glucose, mannose, fructose, etc., from the cellulose and hemicelluloses. The various hexoses may be further degraded to short-chain acids, alcohols, ketones, and aldehydes. The pectins yield methanol and glacturonic acid. The major products from lipid degradation are fatty acids and glycerol. Proteins are successively hydrolyzed into peptides and amino acids.

The net result of organic degradation during this phase of digestion is to convert many of the insoluble raw materials into soluble intermediates. This produces a sufficient concentration of organic acids to depress the pH and essentially stop anaerobic digestion. For this reason, batch digestion of animal wastes is not operable. The acid-forming phase must be conducted in the presence of organisms that can utilize the intermediates.

Acid Recovery Phase

To maintain anaerobic digestion, the intermediates of raw-material breakdown must be converted to suitable end products. This process is the conversion of the intermediates to successively simpler compounds. Hexoses yield shorter-chain acids and alcohols with fewer carbon atoms than do the fatty acids and glycerols. Amino acids are broken down into the ammonium ion and appropriate acids. Hydrogen sulfide and various mercaptans are produced from the sulfur-containing amino acids.

The methane bacteria are responsible for converting the short-chain (1 to 6 carbon) acids and alcohols to methane and carbon dioxide. Thus, methane bacteria prevent a buildup of acids within the system. For this to occur, a proper balance is required between organic feed rates and methane bacteria population.

Methane bacteria are strict anaerobes and require the presence of an ammonium ion as a nitrogen source. Several species have been isolated, each having specific substrate requirements. As an example, *Methanobacterium suboxydans* utilizes butyrate and valerate, but not acetate. Several other species are able to utilize acetate, but no single species is able to utilize the full range of substrates.

Tracer studies have shown that methane formation proceeds in two separate ways. Methane may be formed by the reduction of carbon dioxide by hydrogen.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

The second type of reaction involved in methane production is represented by the decarboxylation of acetic acid.

$$CH_3CO_2H \rightarrow CH_4 + CO_2$$

Considerably more work is needed to reach a full understanding of the methane bacteria. Little is known concerning the enzymes that moderate the various reactions. Only recently have the various species been isolated in pure culture.

Environmental Requirements

The anaerobic-digestion process is a complex one, and environmental control is the primary means man can use to influence it. The environmental factors of primary importance include temperature, pH, and the presence of toxic materials.

Temperature

Like other biological processes, anaerobic digestion is quite temperature sensitive. Even more important, however, is the need for a stable temperature in maintaining a proper balance of acid-producing and acid-utilizing bacteria. Temperature variations produce changes in the relative bacterial specie populations required to maintain this balance. In practice, two temperature ranges are generally recognized for effective anaerobic digestion. Mesophillic digestion (33 to 37 C) is the most common, but thermophilic digestion (53 to 57C) is somewhat more efficient. The increased operating problems involved in maintaining a digester at the higher temperature generally, however, have discouraged the practice.

Various schemes have been presented to correlate the influence of temperature on digester performance. Table 18 presents the time required to obtain 90% of the ultimate gas production in domestic sludge digesters operating at various temperatures.

pH

Most anaerobic-digester malfunctions are related to pH in some manner. The optimum pH for anaerobic digestion is about 6.5 according to McKinney

Table 18. Time required for 90% anaerobic digestion of municipal sewage sludges at various temperatures.

Temperature (F)	Time (days)
60	56
80	30
100	24
120	16
140	18

Source: Amer. Soc. Civil Engin. Sewage treatment plant design. Manual of Practice 36. p. 209. 1959.

(10). When the pH falls below this level, methane bacteria are inhibited by the free hydrogen-ion concentration. As the pH increases above 6.5, the volatile acids (formic, acetic, proprionic, butyric, valeric, hexonic, heptonic, and octonic) increasingly are transformed to their salts, which are unavailable to the bacteria.

The most frequent cause of low pH in anaerobic digestion is a shock loading of organic material that stimulates the facultative acid-producing bacteria. These organisms respond much more rapidly than do the slow-growing methane bacteria, thereby producing low pH, which further inhibits the methane bacteria. This also explains why the anaerobic-digestion process often is difficult to establish. To avoid this problem, anaerobic digesters frequently are seeded with sludge from an operating unit in which a proper bacterial population exists.

The concentration of volatile acids in a digester is frequently used as a diagnostic analysis. Volatile acids (VA) generally increase before the pH decreases. Thus, an increase in volatile acids may indicate a digestion problem that can be overcome before more severe problems are created.

Toxic Materials

Being a biological process, anaerobic digestion is subject to interference by toxic materials that inhibit or kill bacterial cells. Hydrogen-ion concentration, pH, most commonly adversely affects digesters; heavy metals, salts, and the more dramatic poisons of our day, however, are known to present potential problems.

Evaluation of toxicity problems in digesters has proved as difficult as evaluating animal toxicity. The toxicity is generally a function of the existing environmental conditions, the health of the system, the concentration of the potential poison, and the the concentration of other ions within the system.

Among the heavy metals of importance in anaerobic digesters are copper, hexavalent chromium, nickel, and zinc. All these have been implicated in digester toxicity problems, but definite toxic limits are difficult to determine. Values in the range of 200 mg/l. are commonly reported; the amount of metal in true solution, however, is much lower than in digesters.

In order of increasing toxicity, the following cations have inhibited anaerobic digestion: (a) calcium, (b) magnesium, (c) sodium, (d) potassium, and (e) ammonium (9). These toxicities are such that up to 10,000 mg/l. of volatile acids may be neutralized safely with calcium or magnesium hydroxide, but not with sodium, potassium, or ammonium hydroxide. The antagonism between ions is such that combinations of ions are much less inhibitory than a single ion. As an example (3), 2,370 mg/l. of NaCl as Cl^- severely inhibited anaerobic digestion, although 2,370 mg/l. of Cl^- as both sodium and calcium chloride showed negligible inhibition.

Laboratory Results

The feasibility of anaerobic digestion as a treatment process for animal manures has been demonstrated amply by laboratory studies. These studies have been conducted utilizing daily manure feeding, essentially complete mixing, and constant temperature. The operating parameters were essentially those of normal sewage sludge digesters. Table 19 summarizes a number of laboratory anaerobic digestion trials.

The anaerobic-digestion process depends upon contact between enzymes secreted by the bacteria and food material. This mixing-contact requirement, along with the physiological water requirement of bacteria, requires the solids content within a digester not to exceed 10%. This is no problem in most systems inasmuch as sufficient water is used in handling the manure to lower the solids concentrations between 2.5 and 5%. Organic loadings on anaerobic units are expressed as pounds of volatile solids per cubic foot daily. Volatile solids generally are considered a suitable measure of organic matter.

At 35 C, 0.3 to 1.0 ft^3 of gas are produced per ft^3 of digester capacity. Higher values are produced with increased loading rates, and as would be expected, ruminant wastes produce gas at a lower rate than those of nonruminants because of the high concentration of biologically resistant materials.

Anaerobic Lagoons

Anerobic lagoons have found widespread application in the treatment of animal wastes because of their low initial cost, ease of operation, and, perhaps more importantly, the lack of alternatives. As a treatment system, lagoons developed by a trial-and-error process from their distant relative, the municipal aerobic waste-stabilization pond. There is little similarity between an anaerobic lagoon and an aerobic waste-stabilization pond in terms of the processes involved, and many of the characteristics transferred from one to the other have proved detrimental. As an example, aerobic waste-stabilization ponds depend upon the presence of free oxygen for proper functioning; thus, a large surface area is beneficial for oxygen absorption from air and algae stimulation by sunlight. In contrast, oxygen is detrimental to the methane bacteria of anaerobic lagoons so that a maximum surface area is not desired. Aerobic waste stabilization ponds are designed shallow to achieve maximum oxygenation, while anaerobic lagoons should be as deep as practical to achieve maximum temperature stability and to minimize the escape of odors from the water surface.

The anaerobic-digestion process is the same, whether in a laboratory reactor, an operatng digester, or an anaerobic lagoon. Lagoon design is improved by incorporating whatever features are possible from the more efficient digesters without sacrificing their low-cost features. The design features of anaerobic lagoons discussed in this report are the result of experience in various parts of the country. This experience has shown lagoons to be useful components of an over-all scheme for animal-waste treatment. They have provided manure storage in northern climates where winter spreading is not feasible. In such areas, the goal is to provide the necessary storage without creating water-pollution problems or offensive odors. In the central and southern United States, lagoons have provided significant organic decomposition as well as manure storage. Again, the goal is to achieve these results without creating offensive odors or water-pollution problems.

Trends to larger animal-confinement units are resulting in new demands on manure-handling and disposal facilities. Hydraulic manure-transport systems require the treatment of more dilute wastes. For these installations, lagoons are designed to provide significant organic removal from the water, solids storage and volume reduction, and low levels of odor production.

Table 19. Performance of laboratory anaerobic digesters being fed animal manures.

Manure	Temp. C	Loading[a]	Gas prod. ft^3/lb. VS destroyed	Lb. VS destroyed /ft^3-day	Ref.
Poultry	23	0.17	5.1	0.042	5
"	35	0.17	9.5	0.055	5
"	23	0.28	5.3	0.207	5
"	35	0.31	10.7	0.049	5
Dairy	23	0.13	11.0	0.011	5
"	35	0.12	16.2	0.015	5
"	23	0.20	16.1	0.010	5
"	35	0.22	14.3	0.028	5
Swine	35	0.20	–	–	6
"	35	0.15	13.0	0.075	7
Cow	36	0.15	6.4	0.065	7
"	36	0.22	5.0	0.115	7
Sheep	35	0.15	6.0	0.059	7
Cattle	36	0.10	5.0	–	8
"	36	0.40	6.0	–	8

[a]Lb. VS/ft^3 daily.

Loading Rates

Loading rates, which prescribe the design volume of anaerobic lagoons, have been reported by investigators from various parts of the country. These have been based on observations of units in which an adequate balance of acid-producing and acid-utilizing organisms have been established. In such units, offensive odors are minimized, and sludge removal is required on an infrequent basis. Table 20 summarizes some of the reported lagoon loading rates found operable. (2, 3, 4, 6, 14, 15).

Using the average daily volatile solids contribution of various animals discussed previously, the recommended loading rate is from 0.001 to 0.01 lb. of volatile solids per cubic foot daily. This 10-fold range in values is not excessive when one considers the variability of climates from which the data arise. In the design of a lagoon, one should be guided by the climatic conditions in which it will operate. For moderate midwestern climates, a lagoon loading rate of 5 lb. VS per 1,000 ft^3 seems reasonable. Lagoon sizes for various animal wastes are given in Table 21. The capacities given in Table 21 assume that the complete waste load from the animal will be discharged into the lagoon, but no provision is included for bedding.

Under severe winter conditions, little biological activity takes place in anaerobic lagoons. Upon warming, the manure previously deposited in the lagoon becomes available to the facultative acid-producing bacteria. It is at this time that adverse odor conditions are most likely.

Conservative lagoon loading rates are helpful in minimizing this condition, but are not always successful.

The loading rates given in Table 21 do not provide long-term storage space for digested sludge. When lagoons are designed based on these criteria, one may expect to remove sludge at intervals of 1 to 3 years. Larger lagoons may be used to extend the period between sludge removal. The sludge from a lagoon may be sprayed or spread on farmland or dried on sand beds for use by gardeners. The sludge should be essentially odor-free and unattractive to flies or rodents.

Table 20. Reported anaerobic lagoon volumes being successfully used for the treatment of animal manures.

Animal	Lagoon volume ft^3/animal	Location	Reference
Swine	130 to 260	South Dakota	4
Swine	475	Illinois	2
Swine	124	California	6
Poultry	14.6	South Dakota	4
Poultry	6	California	3
Poultry	13.6	California	6
Cattle	1,547	Wisconsin	15
Cattle	795	California	6
Swine	135	Iowa	14

Table 21. Recommended anaerobic lagoon volumes for swine, cattle, and poultry, Central U.S.

Animal	Lagoon capacity[a] ft^3/head
Swine (100 lb.)	125
Cattle (1,000 lb.)	1,500
Poultry (5-lb. hen)	10

[a]Required capacity may be increased up to 50% in areas of severe winters or where infrequent manure removal is important. Warm winter climates may justify capacity decreases of 25%.

Additional Lagoon Design Features

Although the loading rate is the most important single design feature of anaerobic lagoons, other features are important in obtaining a satisfactory facility.

1. **Depth.** Lagoons operate on a volumetric basis; therefore, no benefit is gained by making them shallow to maximize the surface area. Deeper lagoons provide greater temperature stability and a minimal surface area for the escape of odors. For these reasons, anaerobic lagoons should be constructed as deep as is feasible economically while maintaining the bottom above the groundwater elevation. Depths of 12 to 14 ft or more have proved popular and seem satisfactory.

2. **Sealing.** To perform satisfactorily, lagoons must not show appreciable seepage. Exfiltration presents an immediate threat to groundwater supplies of an area. Before construction is begun, be certain that an impervious seal can be achieved. In certain locations, soil additives, such as bentonite clay and various polyphosphates, have proved helpful. Where problems arise or doubts exist, consult an expert on the performance of soils in the area.

Related to seepage losses is the matter of maintaining a satisfactory water level within the lagoon. When the water surface is below the design level, excessive organic loads per unit volume are placed on the unit. In addition, exposed solids are attractive to flies and are likely to produce odors. When considering the construction of a lagoon, give serious consideration to the water balance. When exfiltration is high, maintaining proper water levels may present even more serious problems.

3. **Shape.** Improved lagoon operation may be achieved if some consideration is given to a lagoon shape that will facilitate natural mixing and prevent dead spaces within the unit. Circular and rectangular lagoons have been used; a rectangular lagoon, however, should have a length to width ratio of 3:1 or less. Also to be avoided are natural shaped lagoons with narrow appendages easily isolated from the remainder of the system. These sections generally contribute little to the operation of the system and may be a source of nuisance conditions.

4. **Dike Slopes.** Dikes should be designed to resist severe erosion damage when grass cover is being established. Furthermore, they should not be so steep as to preclude safe mowing of the grass cover once established.

5. **Inlets and Outlets.** Raw manure should enter away from the edge of a unit, preferably near the center. Where sufficient flow exists to the lagoon to maintain the influent line free of obstructions, a submerged inlet is desirable to aid mixing and to avoid winter freezing problems. Where problems may be anticipated due to flow obstructions, a discharge above the water surface facilitates cleaning and inspection. Troughs rather than pipes have been utilized in some installations to prevent flow stoppages as well as to allow cleaning and inspecting troublesome lines. Troughs also may be used to move manure with less water than is needed with pipes.

Many lagoons are operated so that no discharge is necessary. Thus, water quality in the receiving stream is not damaged. To avoid discharge from a lagoon, the water lost by evaporation and seepage must equal the average raw-waste flow. Since seepage is minimized for groundwater quality protection, one may write the following water balance:

$$A(E\text{-}R) = PQ$$

R = Annual rainfall rate, inches/year
E = Evaporation rate, inches/year
Q = Daily waste flow, gallons
P = Conversion factor, 0.0134
A = Surface area of lagoon, acres

This expression is useful in predicting the size of lagoon required for evaporation of the incoming water during an average year. To be prepared for extreme seasons, construct extra freeboard in the lagoon for water storage and have supplemental water available for the initial start-up and for use in dry years.

In areas of high annual rainfall, it is not feasible to design a lagoon for evaporation of all the incoming water. In such instances, outlets must be provided, and plans made for proper disposal of the effluent. Effluent may be spread on nearby land as enriched irrigation water or discharged to surface streams after appropriate further treatment. In some locations, where sufficiently large receiving streams exist, discharge of lagoon overflow without further treatment may acceptable.

Lagoon outlets, where used, should be designed to remove an effluent of the best possible quality whether it is to be further treated for reuse or applied to land. The material of best quality is generally near the surface, but below any scum layer that may exist. Outlet lines may be sloped through the dike to prevent scum carryover or may be fitted with some type of scum retention baffle on the lagoon side of the dike.

6. **Surface Grading.** The area around a lagoon should be shaped to prevent surface runoff from entering the lagoon. Such water tends to dilute the active material within the lagoon, reduce the over-all detention time, and cause unnecessary effluent discharge.

Also related to surface grading is the matter of preventing unnecessary waste production by the contamination of clean water. This aspect is particularly important in treating runoff waters from animal feeding areas. All waters not falling directly on the animal confinement area should be diverted around it and prevented from entering the lagoon. Where extensive roofed areas are involved, roof drains should be collected so that this clear water is kept from manure contamination. In this way, one can reduce significantly the size of treatment facility required—and at the same time decrease the amount of material for which final disposal is required.

7. **Fencing.** Lagoons should be fenced for the protection of children or livestock. The fence should be located so that it will not interfere with maintenance of the dikes or mowing of the area. Adequate gates are needed to allow access of mowing and maintenance equipment.

Lagoon Performance

Anaerobic lagoons have been used under a great variety of conditions for the treatment of animal wastes. These conditions have included different lagoon designs, environmental conditions, and operating schemes. In many installations, evaporation and infiltration have been sufficient to make discharge unnecessary. Thus, these lagoons might be considered 100% successful as waste disposal devices. Where discharge is required, the effluent generally is considered as being inadequately treated for discharge into dry or intermittent watercourses. Lagoon effluent may be of satisfactory quality for discharge into certain larger streams where sufficient dilution water is available to prevent water quality problems (Table 22).

Table 22. Anticipated results of a properly operating anaerobic lagoon receiving animal wastes in a moderate climate.

Item	Effluent compared with influent
BOD concentration	70 to 90% reduction
Settleable solids	Nearly complete removal
Total solids	60 to 80% reduction
pH	Little change, remains neutral
Ammonia nitrogen	Large increase

Heated Anaerobic Digesters

Laboratory studies have demonstrated the usefulness of heated anaerobic digesters in the treatment of animal wastes; the process, however, has not been attractive to commercial animal producers. This unit would involve a higher initial cost than does the construction of a lagoon and would require more sophisticated management. In return, this unit offers a higher degree of organic removal, the production of a useful gas, an escape from the problem of lagoon odors, and a means of preventing groundwater pollution.

Design Features

Until anaerobic digesters have gained acceptance in the treatment of animal wastes, only tentative design criteria can be established. These, of necessity, are based on laboratory observations and operating results where this procedure has been used for the treatment of other organic wastes.

1. **Loading.** Anaerobic digesters would logically be designed on the basis of weight of volatile solids per unit volume at a specified temperature. From the research data available, a loading of 0.2 lb. of volatile solids per cubic foot daily seems a reasonable design basis for a unit operating at 35C. This

leads to the volumes suggested in Table 23 on a per-animal basis.

2. **Dilution.** Adequate water is always available when manure is hydraulically transported to the treatment facility. Where manure is handled in a dry state, sufficient water should be added to reduce the solids content to 5 to 10%. Higher solids concentrations generally interfere with active anaerobic fermentation and complicate thorough mixing.

3. **Mixing.** Adequate mixing is essential in the operation of a high-speed anaerobic digestion process. Mixing brings fresh manure into contact with the bacteria capable of metabolizing it. Furthermore, mixing allows the full buffering capacity of the digested sludge to be utilized, prevents the development of unused "dead" spaces, and maintains a uniformly active bacterial population.

Several schemes may be used for the mixing of an anaerobic digester. Continuously pumping from the bottom through a centrifugal pump and discharging into the top of the tank is a popular way of sludge mixing. This technique maintains all the equipment outside the tank for easy maintenance. Alternately, either gas or mechanical mixing may be practiced within the tank. Where gas mixing is utilized, some of the gas produced by the digestion process is compressed and discharged near the bottom of the unit. Mechanical mixing involves the installation of some type of mechanical agitator within the tank, coupled to an exterior power supply.

4. **Heating.** Adequate temperature control is essential for high-rate digestion. A temperature of 35 C is desirable for adequate digestion and attainable in practice without undue difficulty. Where mixing is accomplished by pumped recirculation, it is generally convenient to place a heat exchanger in this system after the pump. Heating coils or pipes within the digester generally have been found difficult to maintain.

Digester covers may be fixed or floating. Floating covers provide a variable gas-storage volume within the digester, which in many instances eliminates the need for exterior storage. Fixed covers, however, are somewhat easier to construct and cheaper.

Piping associated with the digestion tank should include facilities for waste addition, digested sludge removal, settled effluent removal, gas collection, and recirculation. The piping material should be selected to be resistant to the corrosive conditons expected and of sufficient structural strength to meet the demands of the system. In the past, cast-iron piping has been the material of choice for most municipal digesters. Other piping materials may prove suitable in the future.

5. **Digester Gas.** The gas produced by an anaerobic digester treating animal wastes may be expected to be about 60% methane and 40% carbon dioxide (13). This gas has a heating value of 570 BTU/ft^3. The quantity of gas may be somewhat variable but 7 to 10 ft^3 per pound of volatile solids fed the unit may be expected under conditions of good digestion.

To utilize the gas produced in anaerobic digestion, it must be collected, stored, and burned in a controlled manner. Limited volumes of gas may be stored within the digester, and such storage may be sufficient if a uniform gas rate is envisioned. Where variable gas demands are planned, separate gas-holding and, in some instances, compression, are advisable. Gas systems must include the necessary safety features to prevent explosion damage to equipment. Minimum features normally include a vacuum and pressure relief, a flame trap, and a pressure-regulating system.

Table 23. Suggested volume of heated anaerobic digester for wastes of various livestock.

Animal	Anaerobic digester Volume per head, ft^3
Cow (1,000 lb.)	45.0
Swine (150 lb.)	5.0
Poultry (5-lb. hen)	0.5

Expected Results

A properly operating digester may convert at least 75% of the entering organic solids into gas and convert the remainder to a sludge less offensive and more easily handled than fresh manure. The liquid effluent, or supernatant, from a digester is amenable to further biological treatment before discharge or reuse. This organic material will have been stabilized for considerably less cost than if similar results had been achieved with an aerobic system. In addition to the reduced operating costs, the gaseous by-products may be claimed for energy production.

Combined Anaerobic-Aerobic Systems

Effluent from anaerobic treatment units has been demonstrated to be amenable to further aerobic biological treatment. The meatpacking industry has been among the leaders in this form of complete waste treatment. A typical system would utilize a mixed anaerobic lagoon with a detention of 7 to 10 days in which the incoming waste would be mixed with sludge recirculated from the bottom. From the anaerobic cell, the liquid flows into an aerated chamber with a detention of from 1 to 3 days. In this chamber, aerobic organisms feed on the immediate breakdown products left by the anaerobic organisms of the previous step. This aerobic unit is the more expensive of the two, since it requires mechanical aeration to maintain a dissolved oxygen concentration of roughly 2 mg/l. or more at all times. After aeration, the waste flow is then diverted to an aerobic lagoon for further sedimentation and clarification. In many instances, these units have been designed to provide for treatment as well as storage of the waste during low-flow periods in the stream. In such a system, one may select the time of year when the discharge will occur. Many aerobic cells have been designed for

60 to 90 days detention. Data currently available for this treatment scheme indicate a BOD removal of 95% or greater for most of the year. In these units, the anaerobic cell provides approximately 70% of the total organic destruction.

This form of treatment may be expected to become more important in the technology of handling waste in the future. This would involve the combination of units currently available; namely, the anaerobic lagoon and the oxidation ditch or modified activated-sludge unit into a single processing system. Such a system would require the improvement of our current lagoon design and operating procedures, with the possible addition of mixing or heating the facilites. The final design of such a unit must await further research and testing to determine the proper design parameters and operating procedures.

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UTILIZATION OF FARM ANIMAL WASTE

Direct disposal of animal wastes onto the land as fresh manure or after short-term storage has been the traditional practice of the animal industries. The practice remains attractive in many areas because the return to the soil of nutrients harvested in crops is a logical way to help build or maintain soil fertility. Manure also has been shown to improve soil tilth, increase water-holding capacity, lessen wind and water erosion, improve aeration, and promote the growth of beneficial soil organisms. The practice of land disposal of animal wastes developed largely through the desire to increase crop production rather than as a means of disposal as the primary objective.

Confined feeding, however, has raised certain questions regarding the feasibility of land disposal of manures in some areas. Where large quantities of wastes are generated in concentrated areas, the logistics of land disposal in the traditional sense sometimes present formidable problems. Direct land disposal of manures from large livestock enterprises located in areas of dense population often becomes a nuisance because of flys and odor. The maintenance of water resources at a satisfactory quality level also has become an important public issue. Spreading animal manure throughout the winter in the northern states may be a source of some water pollutants. Thus, there are two approaches to the animal-waste-disposal problem. Animal waste may be treated as an unwanted waste to be reduced and disposed of by any available means publicly acceptable, trouble-free, and economically feasible. Otherwise, it can be treated as a resource, its values conserved, and its use developed for optimum benefit.

Where winter spreading of manure is practiced and there is danger of water pollution during winter thaws and spring rains when the soil is still frozen, adequate storage facilities are needed until after the frost is gone and the soil is in suitable condition to receive the manure. A storage period of from 120 to 180 days is required. Such storage facilities should be designed to minimize losses of the fertilizing nutrients caused by volatilization, leaching, and seepage, as well as to meet state and federal sanitation requirements. Three types of storage include anaerobic tank, aerobic lagoon, and stack. Before changing present methods of manure handling, farmers will want to know how such changes will affect the fertilizing properties of the manure. Since most farmers in the North Central Region of the United States are likely to continue to find the practice of land disposal of animal wastes the most economical and satisfactory method; the discussion that follows will be concerned largely with this means of disposal, particularly as it relates to methods of handling.

Economic Value of Manure

Numerous workers have reported on the value of farmyard manure for increasing the yields of a number of crops, including those in rotation, on a wide range of soils (3, 7, 19, 22, 25, 27, 29). Some of the higher yield responses obtained per ton of manure applied for corn in a rotation were 3.8, 1.5, 1.3, and 1.3 bu per acre for corn grain, wheat, barley, and soybeans, respectively, and 145 lb. for hay. Most workers reported that the high rates of manure resulted in higher crop yields, but that the lower rates gave higher returns per ton of applied manure. Recovery values from manure by various crops ranged from about 10 to 30% for N, 10 to 20% for P, and 30 to 100% for K (2, 24, 30, 31). These values are comparable to those reported in the literature for crop recovery from applications of commercial fertilizers.

The value of increase per ton of farmyard manure applied for corn or wheat in a corn-oats-wheat-clover-timothy rotation at Wooster, Ohio, over a period of 33 years was $3.39 for grain crops at the 8-ton-per-acre rate of application and $2.86 at the 16-ton-per-acre rate (25). Rost and Kramer (22), in Minnesota, found that each ton of farmyard manure was worth $4.72 for an 8-ton-per-acre application for first-year corn in a corn-corn-oats-hay rotation. Weideman and Millar (28), in Michigan, found that each ton of manure was worth $4.46 for a 5-ton-per-acre application for corn in a corn-barley-wheat rotation and declined to $3.82 and $3.02 for 10- and 15-ton-per-acre rates, respectively.

Frequently, the value of farm manure is calculated on the basis of the value of its N, P_2O_5, and K_2O contents. At current delivered prices of about 10, 9, and 4¢ per lb. for the respective constituents in dry, mixed fertilizers in many areas of the north-central states, the value of a ton of average dairy-cow manure containing 10 lb. of N, 5 of P_2O_5, and 10 of K_2O would be about $2. This figure is appreciably lower than those just cited for the value of farmyard manure in terms of the increased yield that it will produce. No doubt, there are other benefits provided by the manure, such as its supply of trace elements and the energy material it contains for stimulating the activity of soil microorganisms.

Effect of Method of Handling, Application Rate, and Drying on Yield and Nutrient Recovery

Manure applications that result in considerable yield increases suggest that soil fertility had not been adequately maintained (10). Light rates of manure application over a large cropland area often result in greater returns than do heavy applications on a small area. A number of researchers have noted that the lowest losses of N and best crop yields generally occurred for manure kept moist during storage and incorporated into the soil before drying occurred (23, 25, 27).

Hensler (11), in Wisconsin, found that, on the average, fresh, fermented (piled) and anaerobic, liquid, dairy-cow manures gave similar increases in yield but that both gave yields that were superior to those from aerobic liquid manure applied to Miami silt loam in the greenhouse (Table 24). Similar trends were noted for steer manure. The 30-ton-per-acre rate of application resulted in up to 20% greater yields but 5 to 10% lower percentage recovery of N and P as compared with the 15-ton-per-acre rate. Average recovery of N by the crop ranged from 18.5% for aerobic liquid to 52.5% for anaerobic, liquid dairy-cattle manures. Average recovery of P ranged from 19.5% for aerobic liquid to 29% for anaerobic, liquid, dairy-cattle manure. Recovery of N and P from steer manure generally was greater than from dairy-cattle manure. Allowing the manure to dry 1 week before incorporation usually gave 10% lower yields and 5 to 40% lower recovery values for N, P, and K.

Research data from Pennsylvania indicate that crops contribute very significantly to the removal of nitrogen applied in waste water. For example, silage corn removed 3% more nitrogen than was applied in waste water when the nitrogen application rate was approximately 100 lb. per acre of N (13, 21).

Table 24. Effect of method of handling of dairy cow and steer manures on average yield and recovery of N, P, and K by one crop of corn grown on a Miami silt loam in pots.

Type of manure[a]	Yield[b]	Recovery by crop[b] N	P	K
	g/pot	%	%	%
No manure	11.0	–	–	–
Dairy cow				
Fresh	19.5	44.0	19.5	40.5
Fermented	19.5	42.0	22.5	49.5
Aerobic liquid	17.0	18.5	19.5	38.0
Anaerobic liquid	22.5	52.5	29.0	48.0
Steer				
Fresh	32.0	53.0	23.5	73.5
Fermented	32.5	54.5	23.5	74.0
Aerobic liquid	20.5	13.0	14.5	34.5
Anaerobic liquid	33.0	65.5	27.5	83.0

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis including 2% oat straw. Tons/acre = tons/2,000,000 lb. of acre furrow slice.

[b]Average of three replications and drying treatments; recovery values calculated on fresh-weight basis for manure.

Source: R.F. Hensler, Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

Effect of Rate of Application and Liming on Yield

The maximum or optimum rates of disposal on land have not been established. Rates undoubtedly will be influenced greatly by soil type and properties of the subsoil, possible accumulation of toxic elements in the soil, and the possibility of polluting groundwaters. The literature indicates that hydraulic loading rates of organic industrial wastes on land ranging from 2,500 to 50,000 gallons daily per acre and BOD loadings of from 10 to 2,000 lb. daily per acre have been used (26). Because of this wide range and because animal wastes differ significantly from most organic industrial wastes, it seems that much more research will be required before reliable criteria can be developed for maximum rates of disposal for animal wastes.

As a general guide, manure spread at the rate of 10 tons per acre on some soils has caused lodging of small grains. Research plots of corn have been reported as tolerating 100 tons per acre, but increase in corn yields for manure rates higher than the 10 tons per acre rate were quite small.

Scattered reports of seed-germination inhibition are found in the literature pertaining to the disposal of municipal sewage effluents. Usually, a salt effect is cited as the cause of the inhibition. Uneven development of corn plants was observed in one instance in Kansas, where beef-cattle manure was applied to land at about 50 tons per acre a few weeks before planting. Chunks of raw manure surrounding seeds in a row were suspected as a possible cause[4]. The University of Illinois (12) conducted research to determine the effect of digested municipal sewage sludge on germination and seedling development of corn and soybeans. Digested sludge had inhibited seed germination, and the cause probably was ammonia dissolved in the liquid phase. After aerobic fermentation of the digested sludge for 1 week, the inhibiting property was lost. Greenhouse experiments with corn planted 1 inch deep in a sandy soil showed that a 0.5-inch application of fresh digested sludge hindered seedling development. Seed germination and seedling development were good with a 2-inch application of digested sludge that had been aerobically fermented for 1 week.

In Wisconsin studies[5], rates of dairy cow manure ranging from 0 to 270 tons per acre (wet basis) were added to an unlimed (pH 4.5) and limed (pH 6.8) Ella loamy sand in the greenhouse to determine the effect on yield of three successive corn crops (Table 25). On the limed soil, both the individual and total yields increased with each increment of manure. On the unlimed soil, however, yields of the first crop increased through the 30-ton-per-acre rate, then decreased at higher rates. The decrease in yield was probably due to the presence of excessive amounts of NH_4-N or NO_2-N. Average total yields were about the same on the unlimed and limed soil. The data suggest that, where excessively high rates of manure are added to quite acid soil for corn, this should probably be done 6 to 8 weeks before planting.

[4]R.I. Lipper. Unpublished data. Kansas State University. Manhattan.

[5]R.F. Hensler. Unpublished data. University of Wisconsin. Madison.

Table 25. Effect of liming and application of fresh dairy-cow manure to an Ella loamy sand on the dry-matter yield of three successive corn crops grown in the greenhouse.

Manure application rate[a]	Crop yield[b] 1st	2nd	3rd	Total
tons/acre	g/pot	g/pot	g/pot	g/pot
Unlimed				
0	2.3b	4.6a	6.4a	13a
10	5.7c	10.3cd	6.3a	22b
30	10.2de	14.6e	7.8ab	33d
90	5.5c	21.6g	20.6d	48e
270	0.3a	19.1fg	30.7e	50e
Av.	4.8	14.0	14.4	33
Limed				
0	5.2c	7.8bc	9.8bc	23b
10	5.5c	8.5bc	10.7bc	25b
30	8.2d	7.6b	11.3c	27bc
90	8.5d	11.4d	12.5c	32cd
270	11.5e	16.9ef	20.7d	49e
Av.	7.8	10.4	13.0	31

[a]Manure applied on fresh-weight basis.
[b]Values accompanied by the same letter are not statistically different at the 5% level of probability.

Source: R.F. Hensler. Unpublished data. University of Wisconsin. Madison.

Effect of Method of Handling and Bedding Rates on Yield and Nutrient Recovery

Bedding, in addition to its absorptive properties, helps reduce volatilization losses of N on drying, but results in a reduction in the availability of manure N due to a wide C/N ratio (8, 9, 25, 27). Results obtained by Cooke (4) at nine sites on the Rothamsted (England) Experiment Station suggest that the yield increases could be due to the effect of the organic-matter content of the manures as well as the nutrients they contain.

In the Wisconsin studies (11), the results of a greenhouse experiment on a Miami silt loam showed that total dry-matter yields of corn were greatly affected by increasing amounts of bedding up to 8%, but that at the 16% rate, yields usually were much lower (Table 26). On the average, there was no appreciable difference in N recovery values between the oat-straw and wood-shavings treatments, and only small variations occurred in average P recovery due to kind or rate of application of bedding.

Table 26. Effect of type of manure and type and rates of bedding on average total yield and recovery of N and P by two crops of corn grown on a Miami silt loam in pots.

Parameters studied	Total yield[a]	Recovery by crop[a] N	Recovery by crop[a] P
	g/pot	%	%
Fresh manure	62.4b	65.2b	32.6b
Fermented manure	62.7b	73.8c	32.7b
Anaerobic liquid manure	58.4a	58.4a	31.4a
Oat straw	62.9b	64.3a	33.2b
Wood shavings	59.4a	67.4a	31.3a
Rates			
2%	65.1b	78.1c	34.2c
4%	62.8b	75.2c	31.6b
8%	63.6b	66.4b	32.8b
16%	53.2a	43.7a	30.3a

[a]Values accompanied by the same letter are not statistically different at the 5% level of probability.

Source: R.F. Hensler. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

Effect of Method of Handling and Time of Application on Yield and Nutrient Recovery and on Runoff and Nutrient Losses

Fresh manure, incorporated into the soil immediately after application, generally has been found most effective in increasing crop yields (8, 9, 10). Midgley and Dunklee (18) found that the amount of N lost in the runoff from surface-applied manure during the winter was inversely related to the amount previously lost to the air by drying.

The field application of dairy-cow manure in the Wisconsin studies (11) gave increased yields of corn in all instances. On the Rozetta silt loam soil (Table 27), the increases were 1-1/2 to 2 bushels of corn grain per ton of applied manure, but there were no significant differences due to type of manure or time of application. Significantly higher recovery values by the corn crops were obtained for N in the fermented manure and for P in the anaerobic, liquid manure. Winter-applied manure resulted in greater losses of N, P, and K than did spring-applied manure, especially during a January 1967 thaw accompanied by a 3/4-inch rain. On the average, about 39% of the N, 11% of the P, and 42% of the K were accounted for in crop recovery and runoff losses.

The possibility of contamination of groundwaters and irrigation return-flows must be considered where large-scale deposition of animal wastes is contemplated as a means of disposal. The probability of bacterial and viral contamination seems more remote than does chemical contamination (17). Most agricultural soils exhibit a large fixing capacity of P, N being the most likely contaminant to be carried in the leachate. Research indicates that, if large additions of nitrogen to fields are not balanced by withdrawals in harvested crops or denitrification losses, soluble nitrogen may accumulate in surface and underground waters (20).

Groundwater containing nitrate (including nitrite), occasionally in concentrations toxic to humans and livestock when the water is used regularly, has been observed in Kansas, Minnesota, Wisconsin, Iowa, Illinois, Michigan, Montana, Pennsylvania, Missouri, and Colorado[6]. Analysis of nearly 5,000 water samples from rural wells in Missouri showed that about 42% contained more than 5 mg/l. of nitrate-N, a tentative tolerance level for babies(14). The highest concentrations were found in areas with the largest livestock production and shallow wells. There was a high correlation between nitrate occurrence and concentration in these wells and their proximity to livestock feedlots and silos (14).

[6]R.F. Hensler. Private communication. University of Wisconsin. Madison.

Table 27. Effect of treatment of dairy-cow manure and time of application to Rozetta silt loam on 3-year average yield and recovery of N, P, and K by corn and on runoff and nutrient losses.

Type of manure[a]	Time of application	Av. Yield[b] Grain	Av. Yield[b] Stover	Recovered by crop[c] N	Recovered by crop[c] P	Recovered by crop[c] K	Lost in runoff N	Lost in runoff P	Lost in runoff K	Total accounted for N	Total accounted for P	Total accounted for K
		Bu/a	tons/acre	%	%	%	%	%	%	%	%	%
No manure	—	63	2.0	0	0	0	–	–	–	–	–	–
Fresh	Winter[d]	84	2.3	20	5.4	27	7	3.9	23.1	27	9.3	50
Fermented	Spring	97	2.6	44	10.7	46	0.3	1.2	0.3	44	10.7	46
Anaerobic liquid	Spring	91	2.3	45	11.7	30	0.8	1.0	0.3	45	11.7	30

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis.

[b]Three-year average from duplicate plots; treatments followed by the same letter are not significantly different at the 10% level of probability.

[c]Recovery based on analysis of nutrients in fresh manure.

[d]Manure applied on frozen ground in winter and incorporated in spring before planting at the same time as manure applied in spring.

Source: R.F. Hensler. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

Effect of Method of Handling and Placement on Yield and Nutrient Recovery

The impracticality of hauling manure daily throughout the year, because of inclement weather or growing crops, results in the need for some storage of manure in many areas. Fermented manure usually has a higher percentage content of plant nutrients because of the loss of dry weight by organic-matter decomposition, but generally shows no advantage over fresh manure for crops (9, 23, 27). Several workers have concluded that storing manure in a pit or tank is the most advantageous method of conserving its fertilizing value because losses of plant nutrients and organic matter are minimized (23, 25). Also, the addition of small amounts of water with thorough mixing produces a semiliquid that can easily be handled by pumping from the tank for field application. Several workers have suggested that placing manure in a band for row crops may result in better utilization of nutrients from the manure than broadcast application (15, 18, 19, 25, 27).

In the Wisconsin studies (11), corn dry-matter yields on a Withee silt loam soil were significantly lower for fresh manure than for comparable treatments with fermented or anaerobic liquid manures (Table 28). Recovery of N, P, and K by the crops showed trends similar to those for yield. The liquid manure from the tank, knifed in between the rows, resulted in greater yields and nutrient recovery than did liquid manure plowed under. The application of manure also gave higher values for exchangeable K, available P, and organic matter in the soil. These data suggest that manure can be an important source of plant nutrients for crops and in maintaining soil fertility.

Effect of Application Rate of Liquid Manure on Yield and Composition of Alfalfa-Grass Hay.

Results obtained by Turk and Weideman (27) in Michigan indicated that manure applied to legumes may introduce weed seeds, stimulate grass to the disadvantage of the legume, and reduce fixation of atmospheric nitrogen by the legume.

In the Wisconsin studies (11), dry-matter yields and protein content of alfalfa-grass hay was affected very little by liquid manure (20% added water) applications ranging from 0 to 60 tons per acre (Table 29). The most pronounced effect was the increase in grass or weed species over legumes for the summer-applied manure, especially at the 40- and 60-ton rates. This effect was not obtained from the spring topdressing treatment, probably because of rains that occurred soon after application.

Alternative Methods of Application of Manure to Cropland

With most existing methods of applying animal wastes to the land, application cannot be made during the growing season because of possible damage to the crops or on frozen ground because of the pollution hazard. Therefore, sanitary and nuisance-free holding facilities are required. The disposal of wastes in liquid form has gained popularity because of the ease of storage and handling. Holding tanks with 2 months or more capacity have been suggested to provide the needed operational flexibility.

Table 28. Effect of treatment of dairy cow manure and method of application on total dry-matter yield (3-yr. av.) and recovery of N, P, and K by three crops of corn grown on a Withee silt loam.

Treat-ment	Type of manure and time of application[a]	Method of storage[b]	Method of incorpor-ation	Average annual dry-matter yield[c]	Total recovery by crops[d]			Effect of manure on final soil tests			
					N	P	K	pH	Organic matter	Avail. P	Exch. K
				lb./acre	%	%	%		%	lb./acre	lb./acre
1	None	—	–	7,510x	–	–	–	7.4	2.9a	48a	134a
2	Fresh (W)	None	Plowed under	8,125y	7b	5.8bcd	18b	7.3	3.5a	50a	179bc
3	Fermented (S)	Barrels	Plowed under	8,650z	14cd	7.6bcd	31c	7.1	3.6a	66b	222d
4	Liquid (S) (no straw)	Barrels	Plowed under	8,515z	15d	8.2cd	23b	7.2	3.5a	65b	208cd
5	Liquid (S)	Barrels	Plowed under	8,800z	15d	9.4d	31c	7.2	4.0a	63b	204c
6	Liquid (S)	Tank	Plowed under	8,130y	9bc	4.0b	17b	7.4	3.7a	56ab	214d
7	Liquid (P)	Tank	Knifed in mid-way between rows	8,820z	11bcd	4.3b	27c	7.4	3.7a	50a	171b
8	Liquid (P)	Tank	Knifed in 4-6 in. from row	8,885z	15d	4.7bc	27c	7.4	3.8a	58ab	240d

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis; W = winter (Jan.), S = spring (early May), P = after planting.
[b]Some differences in quality of the manure may have resulted between the barrel and tank storage; thus, strict comparisons between the results obtained for the two methods may not be valid.
[c]Treatments followed by the same letter are not statistically different at the 10% level of probability.
[d]Based on nutrients in fresh manure; letter designations same as in footnote c.

Source: R.F. Hensler. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

Thin spreading by sprinklers has been suggested as a disposal method for fluidized manure in arid and semiarid regions (16). The possibility of fly breeding, creation of undesirable odors, and pollution of surface waters, however, would seem to limit use of the method in humid regions. The mixing of manure slurries into irrigation waters also has been practical under some conditions. Attention must be given to recovery of tail water from such irrigation systems if pollution of watercourses is a possibility. The likelihood of spreading pathogens to irrigated crops must be evaluated in selecting the type of irrigation system and crops to be irrigated.

Injection of manure slurries below the soil surface seems to have considerable promise. Two inches of poultry manure were deposited in the bottom of a plow furrow and immediately covered (16). The rate of disposal was estimated at about 200 tons per acre. One of the promising advantages of this method of manure application was that the immediate covering of the wastes greatly reduced the possibility of pollution caused by storm-water runoff. Also, immediate incorporation reduces volatilization losses of nitrogen, reduces odor, and reduces fly-breeding problems. Laboratory investigations have indicated that the molecular diffusivity of the cattle-manure constituents that contribute to pollution is very low (11). On the assumption that other animal wastes exhibit a similar behavior, this means that only those waters actually percolating through plowed-under wastes are likely to pick up manure contamination.

Evaluation of Four Methods of Handling Manure

Some of the findings in the Wisconsin studies (11), along with other available information, might serve as a basis for evaluation of the four methods of handling manure for a given area or set of circumstances. A tentative method of evaluation was devised and is presented (Table 30) as a basis for study (11). For purposes of discussion, consideration was given to an "average" dairy farm in southeastern Wisconsin, where some controversy exists between rural and urban areas with regard to potential pollution of lakes, streams, and air from the spreading of animal manure on the land. In this evaluation, anaerobic, liquid manure stored in a concrete tank and spread on or knifed into the soil when conditions are suitable seems to hold certain advantages. In this case, a higher priority is placed on pollution control of surface water, total labor required, flexibility in time and method of application, and less on seasonal distribution of labor and cost of investment. This method of hand-

Table 29. Effect of rate of liquid manure application to a Withee silt loam soil on dry-matter and protein yields and on plant composition of an alfalfa-grass hay and on certain soil-test values.

Time and rate of manure application[a]	Total Yield[b]		Composition of third cutting[c]			Content in soil after third cutting		
	Dry matter	Protein	Alfalfa	Grass	Other	Avail. P	Exch. K	NO_3-N in. 1st 4 ft
tons/acre	tons/acre	lb./acre	%	%	%	lb./acre	lb./acre	lb./acre
Spring								
0	5.98c	2,000a	50	35	15	129a	248a	105ab
5	5.66bc	1,890a	50	30	20	134a	255a	—
10	5.53abc	1,910a	55	30	15	126a	274a	109bc
20	5.37ab	1,740a	50	35	15	138a	269a	86a
40	5.14a	1,680a	55	30	15	153b	295a	119bc
60	5.41ab	1,760a	60	20	20	163b	296a	129c
Summer								
0	5.65a	1,800a	45	45	10	165a	348a	—
5	5.52a	1,760a	35	50	15	164a	334a	—
10	5.81a	1,820a	35	50	15	165a	341a	—
20	5.61a	1,730a	30	55	15	172a	348a	—
40	5.68a	1,780a	20	60	20	170a	354a	—
60	5.55a	1,660a	5	75	20	171a	395b	—

[a] Spring application of manure made before significant growth had occurred and summer application after removal of the first crop.

[b] Three cuttings taken for manure applied in spring and four for manure applied in summer. Treatments followed by the same letter are not statistically different at the 10% level of probability.

[c] Average of visual estimates made by three people.

Source: R.F. Hensler. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

Table 30. Tentative method of evaluation of four methods of handling manure on an "average" dairy farm in southeastern Wisconsin.

Items of comparison	Relative value for type of manure[a] (No. 1 = most favorable)[b]			
	Fresh	Fermented	Aerobic liquid	Anaerobic liquid
Effect on corn yield	2	1	4	1
Effect on nutrient recovery	3	1	4	2
Effect on labor:				
Seasonable distribution	1	3	3	3
Total required	2	2	1	1
Flexibility in:				
Time of application	3	1	1	1
Method of application	3	3	1	1
Amount of bedding needed	2	2	1	1
Possibility for least pollution of:				
Lakes and streams	3	2	1	1
Air	1	3	2	4
Relative investment cost	1	2	4	3
TOTAL	21	20	22	18

[a]It is assumed that fresh manure generally would be spread daily as produced and that the fermented and aerobic liquid manures (optimum storage) would be applied when conditions were suitable and that the manure would be incorporated into the soil before much drying had occurred.

[b]A difference of more than 1 unit between relative values suggests important or statistically significant differences between items of comparison.

Source: R.F. Hensler. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. thesis. University of Wisconsin. Madison. 1970.

ling could also be effective in air-pollution control if the liquid manure were knifed into the soil or plowed under in the process of application. Anaerobic liquid manure also ranks high as a fertilizer for corn, and there is considerable flexibility in the amount of bedding needed if slatted floors are provided.

Similar evaluations for other areas could give results quite different from those just described. Thus, in areas of relatively level land, low population density, and relatively few pollution-sensitive lakes and streams, it might be advantageous to haul and spread manure daily as produced. In this instance, good seasonal distribution of labor and low cost of investment may be among the most important items for consideration.

Fermented (piled) manure ranks high as a fertilizer for corn, in nutrient recovery by crops, and in flexibility in time of application. It might be contended, however, that, where manure is applied in the spring for corn, this flexibility is quite limited. Its undesirable features include objectionable odor at the time of spreading, certain limitations on method of application and the possibility of leaching of the unprotected piled manure and pollution of the surface water.

From the standpoint of the farmer, the aerobic treatment of dairy-cow and steer manures would likely be the least desirable because of the relatively high cost, reduced value of the manure as a fertilizer for corn, and low recovery of plant nutrients. Also, any method of handling that allows the manure to dry on the surface before incorporation favors the gaseous loss of N and possible pollution of runoff water.

Refeeding of Livestock Waste

A discussion of animal-waste utilization would not be complete without some mention of current attempts to utilize processed-poultry and beef-cattle wastes for use in feeding rations. This practice may have some advantages, but only for those dairy, livestock, or poultry producers ready and willing to assume any risks that may be associated with these practices and within the limits of regulatory agencies. The refeeding of livestock waste may be an important means of waste utilization in the future. Already, paunch manure from ruminants is being recovered from slaughterhouses and commercially sold as feed for fattening cattle.

Defecated manure likewise may have a high nutritional value. In addition to protein, soluble vitamins also are synthesized in the rumen and may appear in relatively high concentrations in the feces and urine. Feces and urine from poultry, cattle, and pigs contain relatively large amounts of essential amino acids. For this reason, and not only because of grain particles present, manure may be a valuable feed (1, 6).

In refeeding studies with poultry, no significant differences in egg production or mortality have been found due to refeeding of dried poultry manure in rations containing up to 40% manure (5). Laying hens fed cattle-feedlot manure, however, laid slightly fewer eggs when the manure level was increased beyond 10%.

Poultry litter has been tested as a feed ingredient for fattening steers (6). The rate and efficiency of gain were slightly higher for steers fed litter-free rations than for steers fed various levels of litter in rations containing comparable levels of crude protein and crude fibers, but there were no marked differences in carcass quality. A taste test involving meat from steers fed a ration, containing 15 to 30% ground-corncob poultry litter, and meat from steers fed the control ration indicated no difference in the taste of the meat. In refeeding trials with cattle manure in Alabama (1), 40 parts of manure were mixed with 60 parts of feed concentrate and refed to fattening steers. In most instances, weight gains were comparable to those for steers fed the control ration.

One of the promising refeeding schemes is called "wastelage." In one experiment, wastelage was made of 57 parts manure and 43 parts hay and was stored in a silo for 3 weeks before feeding (1). The material contained about 57% dry matter and 12% crude protein (dry-matter basis) and made a palatable and nutritious low-moisture silage. In a 126-day feeding trial, steers fed a ration of 40% wastelage, 60% whole shelled corn, and 2 lb. of liquid protein supplement gained an average of 2.57 lb. per day. A group of control steers fed shelled corn and 2 lb. of liquid supplement gained an average of 2.42 lb. per day.

Disease and parasites do not seem to be problems in wastelage feeding, and neither are antibiotics because they are present at very low levels. The possible presence of stilbestrol in the manure has not been a problem thus far, and cows fed wastelage made from steer manure cycled, bred, and calved normally.

Among the problems encountered in refeeding so far is that a hard-surfaced lot is required along with daily scraping to collect the manure. A simpler method of collection will be needed if refeeding is to be carried out on a large scale. Another problem is the lack of acceptance of the refeeding concept by many animal scientists and public health officials. Certainly, there is much to learn about refeeding, and research thus far has been encouraging.

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COMPOSTING, INCINERATION, DEHYDRATION, AND HYDROPONICS

Composting

Composting is a process in which the volatile solids in garbage or fecal solids are digested by bacterial action. Composting may be either aerobic or anaerobic. The aerobic method is most common commercially since it generates very little odor and accomplishes the reduction rapidly and efficiently. Organic solids completely treated by composting are said to be stable. In a stable condition, the solids undergo little or no further decomposition.

Composted material may range from dark brown to dark gray. It normally has a slight musty or earthy odor. Since it is a stable organic material, it serves as humus when added to soil and improves it for plant growth.

Composting reduces the weight and volume of solids being treated. In areas where compost has no commercial value, the process still may be useful, since it reduces the solids that must be transported and disposed of.

Aerobic composting usually is done by windrowing the waste solids on the ground or on paving. Windrows should not be greater than 5 or 6 ft high and not less than 3-½ or 4 ft high. The optimum moisture content for aerobic composting is from 40-70%, depending on the character of the material. The process is slower at the higher moisture contents. Above 70%, the process tends to become anaerobic. To maintain aerobic conditions, the windrows are turned at intervals. The windrows may be turned from 3 to 4 times in the 15-21 days normally required to complete the process. If the moisture content is high, turning may be required every 2-3 days to prevent development of anaerobic conditions.

The temperature increases as the biological activity develops in a compost windrow. Process temperatures range is from 120 to 165 F. Temperatures above 170 F. retard biological activity. Turning has little effect on temperature control, but excessive temperatures can be controlled by lowering the windrow height. In cold weather, greater windrow heights can be maintained to keep the composting temperatures up to the optimum range. Enough heat is generated in the composting process to kill many pathogenic bacteria and eggs of parasites.

Solid wastes from cattle and poultry are being composted successfully. A limited amount of this is being marketed. For material that cannot be marketed, composting may be a practical way to reduce the quantity of waste material that must be disposed.

Incineration

Incineration is a process in which the volume and weight of organic matter is reduced by burning. The combustible fractions of the waste are burned, and the mineral matter is left as an ash. Materials having a low moisture content will support combustion, while materials having a high moisture content will require a fuel supply to maintain combustion. Livestock wastes presently are being incinerated on a very limited scale. It is possible to incinerate with production of a minimum amount of odor that might offend humans. The process is used where human population is dense. It is also being practiced where land is not available for the spreading of waste material.

Incinerating equipment is designed for either batch loading, or continuous-flow operations. Batch loading requires a high amount of labor. It is also inefficient because the incinerator cools each time it is charged. Continuous-feed types of incinerating equipment are more expensive.

Air pollution can be generated by incineration equipment. Smoke from the incinerator can carry odors from the burning organic matter. Afterburners are used on some incinerators to remove the odor from the smoke before it is discharged into the air. Other incinerators incorporate water-spray systems, mechanical fly-ash collectors, or electrostatic precipitators to control the air pollution.

When organic wastes are incinerated, fertility elements are lost. Incineration is therefore best adapted to areas where wastes must be disposed without offending human populations.

The cost of incinerating animal wastes is not well documented. Until further research is done, persons wishing to consider incineration should be advised to contact engineering firms with experience in designing incinerators for other organic wastes.

Dehydration

Dehydration of livestock wastes is accomplished by lowering the moisture content of the material until it reaches the moisture content of the air in which it will be stored. Drying usually is accomplished by the addition of heat.

The removal of water from livestock wastes greatly reduces both the weight and the volume of the materials being disposed. This reduces the management problems associated with the disposal of these wastes. When the material is at equilibrium moisture content with the air, it can be converted into a granular material, which greatly changes the handling characteristics when compared with the characteristics of the wet manure. Augers, bucket elevators, and pneumatic conveyors used for handling other dry, granular solids can be adapted to the handling of dehydrated manure. The manure in a dry state is relatively free of offensive odors. Dehydration, therefore, converts manure into a form that can be handled easily and is inoffensive.

Equipment for dehydrating animal wastes can be in the form of batch types of dryers or continuous-flow equipment. The batch drying equipment require more labor than do continuous-flow systems.

Continuous-flow equipment designed specifically for drying of livestock manure is being developed. One includes an oil burner located at the bottom of the dryer in a firebox, which provides heat for the air that will be used to remove the moisture from the manure. Wet manure is introduced at the top of the dryer and falls onto a moving conveyor. This conveyor moves the manure from one side of the dryer to the other. When the manure reaches the end of the conveyor, it drops onto an inclined surface. The manure moves down the incline until it reaches a grate, where the smaller parts of the dried material fall through. This material continues to move through additional inclined surfaces. Manure too large to fall through the grate is beaten by a drum, broken up, and thrown back onto the incline to be recycled over the grate. Heated air from the burner moves through the dryer, along the inclined planes, and over the conveyor. This device reduces the moisture content of poultry manure from about 75% to about 5 or 10%. One estimate of the cost of drying that has been suggested is 0.7 cent per lb. of water removed.

A manure dryer used by Michigan State University is manufactured by the Dryer Corporation of America, Allendale, Mich. In one test, chicken manure had an initial moisture content (wet basis) of about 80% and only 9% after drying.[7] Test results are shown in Table 31.

At this capacity, the dryer will handle 1 ton of wet chicken manure in 5.6 hours at a cost of $3.95. The ton of wet manure would produce 466 lb. of dry manure. If one hen produces ¼ lb. of wet manure per day, the dryer would require 7 hr to handle the manure from a 10,000-bird house and have an operating cost (fuel and electricity) of $4.83 per day.

A 20,000-bird house could be handled by this unit by operating 14 hr per day. A ton of dried manure would cost (considering fuel and electricity) $16.60 to produce. Depreciation and fixed costs would increase the total for producing 1 ton of dried manure to from $20-$25. An analysis of dried poultry manure from the experimental drying unit is given in Table 32. During drying, 44% of the non-protein nitrogen was lost.

It was estimated from a market survey in 1966 that dried poultry manure can be worth more than $20 per ton as fertilizer.[8] This value then is near the cost of drying a ton of animal waste.

[7] H.C. Zindel. Personal communication. Michigan State University. E. Lansing. 1969.

[8] H.C. Zindel. Personal communication. Michigan State University. E. Lansing. 1969.

Table 31. Test results on a poultry-manure dryer at Michigan State University.

A. Wet manure in 910 lb.	Fuel oil consumed	8.56 gal
Dry manure out 213 lb.	Time of operation	2.55 hr
Water removed 697 lb.	Electricity used	11 KWH
B. Performance is as follows:		
Actual energy consumed (@ 140,000 BTU/gal)		= 1,198,000 BTU
Theoretical energy required (1,135 BTU/lb. of HH_2O)		= 790,000 BTU
Efficiency of energy conversion		= 66%
Fuel cost/lb. water removed (fuel @ 18¢/gal)		= 0.22¢/lb.H_2O
Weight reduction (H_2O removed/wet weight)		= 76.7%
Dried weight as proportion of wet weight		= 23.3%
C. Hourly capacity of the drier:		
Wet manure dried		357 lb./hr
Dry manure produced		84 lb./hr
Fuel oil used		3.35 gal/hr
Electricity used		4.3 KWH/hr
Fuel oil cost (18¢/gal)		60¢/hr
Electricity (2¢/KWH)		9¢/hr
	Total energy cost	69¢/hr
	or 5.6 hr/ton	= $3.87/ton of wet manure

Source: H.C. Zindel. Personal communication. Michigan State University. E. Lansing. 1969.

Table 32. Analysis of manure from the experimental poultry-manure dryer, Michigan State University.

Constituent	% Concentration
Calcium	5.63
Phosphorous	2.53
Nonprotein nitrogen	1.41
Ash	21.22
Crude fiber	16.59
Ether extract	2.10
Protein	10.25
N-free extract	41.26
Water	8.55

Source: H.C. Zindel. Personal communication. Michigan State University. E. Lansing. 1969.

Disposing of the manure on a no-loss basis would mean a great saving to the poultryman. It could mean that he would be allowed to stay in business with this fairly odor-free operation where he might otherwise be closed down for contaminating the environment.

Hydroponics

Hydroponics is a method used to produce plant growth without soil. Nutrients are carried to the plants in a liquid medium. Plant roots are supported mechanically in such a way that they are suspended in the liquid.

Since nutrients are removed from the liquid used in hydroponic culture, the practice may be used in such a way that its major benefit is derived from upgrading waste water. Such a system could be used as a secondary treatment for waste water from anaerobic digesters or lagoons. Part of the benefit of such secondary treatment is the removal of nutrients, such as nitrogen and phosphates, from the water before it is discharged into public waterways. This can help control the buildup of nutrients in lakes and streams that results in excessive growths of algae and other aquatic plants that lead to rapid eutrophication of these waters. The plant growth is a by-product that should have value as feed.

Studies have been carried out in Maryland in which agricultural engineers from the University of Maryland and the U.S. Department of Agriculture have cooperated to determine whether or not hay or silage crops can be grown hydroponically in livestock-waste lagoon effluent.[9]

One method that has been developed as a system for adapting a hydroponic treatment system to a livestock enterprise is to construct a series of long narrow beds for growing the plants. An inert supporting material must be placed in the bed to provide a medium in which the root systems can be supported. A series of trays suspended on the surface of the liquid may serve as the supporting system; it is difficult, however, to control the proper relationship between the trays and the liquid levels. A porous anchoring medium, such as gravel, is the most common supporting system.

The effluent to be treated is introduced into one end of the long narrow beds. As it moves through the beds, nutrients are removed from the water. Water is evaporated into the air from the water surface and through transpiration. The quantity of waste water is reduced to some degree, and water discharged from the beds contains a lowered nutrient level.

The amount of nutrients that can be removed from lagoon effluent that passes through a hydroponic system will be dependent upon a number of factors, including the retention time of the liquid in the beds and the kind of plant material grown. Orchardgrass and timothy do not adapt well to hydroponic culture because their root systems do not develop well in a liquid environment. Tall fescue, rye, brome, and reed canary have produced promising results in experimental evaluations. In one set of tests with 6 days detention time, tall fescue, rye, and reed canarygrass removed about 80% of the original nitrogen and between 60 to 70% of the P_2O_5. The nitrogen content of the liquid at the beginning of the test was 11 mg/l. as inorganic nitrogen. Figure 2 illustrates for the same set of tests the effectiveness of these plants in removing P_2O_5 from lagoon effluent as a function of time. The P_2O_5 content of the effluent at the beginning of the test was 78 mg/l.

Table 33 gives a record of grass yields from hydroponic beds during a period from 29 Sept. 1965 to 31 March 1966 at the University of Maryland.[10]

[9] H.J. Eby. Personal communication. University of Maryland. College Park. 1969.

[10] H.J. Eby. Personal Communication. University of Maryland. College Park. 1969.

Table 33. Grass yields calculated from hydroponically grown cuttings, University of Maryland.

Grass	Period 29 Sept. 65-25 Jan. 66	Period 25 Jan. 66-28 Feb. 66		Period 28 Feb. 66-31 Mar. 66	
	tons/acre[a] green cut	tons/acre green cut	tons/acre hay	tons/acre green cut	tons/acre hay
Brome	6.3	4.46	1.31	3.65	1.02
Reed canary...	4.8	5.00	1.29	5.00	1.47
Tall fescue....	8.5	8.41	1.53	7.84	1.76
Rye	3.5	5.34	0.925	6.56	1.26

[a] Average of samplings over the period

Source: H.J. Eby, Personal communication. University of Maryland. College Park. 1969.

For the period 25 Jan.-28 Feb., it is assumed that the grass roots have reached sufficient maturity to be effective filters. The figures are based upon a daily effluent discharge of 45,454 gallons. With fescue, 346 lb. of nutrients plus trace elements would be extracted. This does not include those nutrients retained in the root system, which would provide 115 lb. of additional nutrients.

The amount of nitrogen extracted from the effluent and converted to plant cells can be estimated by assuming a 12% protein content for the grass. At this level, 240 lb. of protein would be accumulated in each ton of grass. If 6.25% of the protein is nitrogen, there would be 15 lb. of nitrogen per ton of grass. This is equivalent to 62 lb. NO_3 or 16.07 lb. of ammonia nitrogen.

Data collected on experimental hydroponic beds can be used to determine the bedding requirements for livestock enterprises of various sizes. The calculations shown in Table 34 give the theoretical computations for sizing hydroponic bed areas, based on 100,000 gallons of effluent production per day:

Hydroponic bed size/100,000 gpd @ 5 days detention

(100,000)/7.48 = 13,369 ft^3 @ 1 ft depth = 13,369 ft^2

Liquid volume = 43% of bed capacity when pea gravel is added (based upon displacement measurement).

13,369/43 : x/100 = 31,063 ft^2 of bed 1 ft deep.

Liquid loss/day through evaporation and transpiration 0.128 gal/ft^2 of bed space.

The figures in Table 34 are intended only as indicative rather than precise. Variables such as light, humidity and temperature, and kind of grass would have to be considered. The computations are from bromegrass at 71 F. Humidity was not recorded. A total of 35.0 hr of sunshine was available, or 58% of total daylight. A bed depth of 1.5 ft also can be used satisfactorily. This can reduce the surface area by one-third.

Results of experiments to date indicate that the practice of hydroponics can be used in connection with livestock production systems to control the quality of effluent being discharged in the public water supplies. At the same time, a potential exists

Table 34. Determining hydroponic bed size for 100,000 gallons of water daily on the basis of liquid loss.

Day	Bed size ft2	Liquid Loss gal/ft2	gal.3	gal/ft 3	Correction for vol/area relationship
1st..........	(31,063)	(0.128) =	3,976 gal/7.48 =	532 ft^3 =	1,236 ft^2 bed area
2nd..........	(29,827)	(0.128) =	3,838 gal/7.48 =	513 ft^3 =	1,193 ft^2 bed area
3rd..........	(28,634)	(0.128) =	3,665 gal/7.48 =	490 ft^3 =	1,140 ft^2 bed area
4th..........	(27,494)	(0.128) =	3,519 gal/7.48 =	470 ft^3 =	1,095 ft^2 bed area
5th..........	(26,399)	(0.128) =	3,379 gal/7.48 =	452 ft^3 =	1,051 ft^2 bed area
Total area required = 143,417 ft2 = 3.29 acres				18,377 gal loss: 100,000–18,377 = 81,623 gal discharge per day from initial influent of 100,000 gal	

Source: H.J. Eby. Personal communication, University of Maryland. College Park. 1969.

for the production of nutrient material suitable for further livestock production.

Plant nutrients are a primary cause of water pollution because streams become choked with aquatic growth, including algae blooms. Some present methods for removal of these nutrients are economically infeasible. A hydroponic system could have a relatively low land-area requirement, and a low capital-investment requirement. With a suitable primary treatment, a hydroponic system can provide an effective and economical method of upgrading waste water from livestock enterprises.

FUTURE

The preceding sections have indicated where waste management is today. This section will discuss the future and will be divided into three periods: immediate, foreseeable, and distant.

Any discussion of the future must be based on the past and present situation. Today, livestock operations are specializing and concentrating in animal production and therefore generating large quantities of manures in smaller land areas. Technological changes have brought about a decrease in the cost of production of fertilizers, which has depreciated the relative value of animal manure. Society is changing, and social pressures on urban areas will not allow livestock enterprises to generate dust, odors, flies, and other nuisances that degrade present environmental quality.

The immediate future presents a tremendous challenge to all associated with animal-waste management. This challenge lies in the field of education, and one group that must receive attention is the livestock producers. They must be fully aware of the implications of mismanagement of animal waste. This education must include the far-reaching causes and effects of organic matter, nutrients, tastes, and odors that may result from livestock operations. The industry of agriculture, like all other industries, must and will be required to clean up and properly manage any waste products produced.

The Federal Water Pollution Control Agency is requiring all states to set standards that will upgrade or maintain the quality of their waters. Each of these agencies have regulations that, in turn, set standards for the handling, treatment, and disposal of animal manures. Similar state regulations will require all livestock operators to spend about the same amount of money to employ acceptable waste-management practices.

At the local, state, or national level, an individual or group of individuals charged with water-resource management has the responsibility of making policy decisions on an informed basis. They have a need for technological and economic information regarding this subject area. In too many instances, there is a lack of adequate information for sound regulatory policy decisions. A second challenge is to assist in educating the policymakers about the many phases of animal-waste management. This is not to change their intent or objectives for clean water, but merely to inform them of the problems and facts.

A third major task is one of educating the general public. Agriculture, in general, and livestock operators, specifically, merely serve the general consuming public. They produce, like other industries, goods and services for the general society. If the general society demands from the agricultural industry eggs, meats, and milk from a nuisance-free operation, then society must be willing to pay the price. When the federal government insisted upon safety devices for automobiles, the automobile industry transferred the cost of seat belts on to the consumer. So must be the case for the industry of agriculture. In a society as advanced as ours, where we can send a man to the moon and back, great progress is possible. We have the capabilities and the technical know-how to manage animal waste in an acceptable manner. The general public must be shown that manure, in large quantities, is also produced along with the eggs, meat, and milk.

Waste-disposal research in the immediate future will involve further refinement of existing methods and technology. Researchers will continue to study the physical, chemical, and biological properties of animal waste. As a result of these data, the design parameters of lagoons, aeration ditches, and secondary- and final-treatment systems will be more specifically defined.

Scientists of many disciplines will be attracted to the waste-problem area. This is an inevitable consequence of research monies being made available through government and private agencies. It also will come about because of the immense amount of publicity concerning pollution. Limnologists tell us that nitrates and phosphates are primarily responsible for the undesirable algae blooms in our water resources. Soil scientists are beginning to define plant and soil limits as they are used in waste-treatment systems. Engineers are developing techniques that will remove the major nutrients from animal wastes. Scientists in microbiology and biochemistry will attempt to develop techniques for effectively deodorizing, masking, and digesting odors that arise from livestock and waste-disposal systems. Agricultural engineering researchers have already succeeded in identifying over 25 of the gaseous compounds produced in the storage, handling, and treatment of animal manures. The addition of the appropriate chemical at the time of pumping and spreading will allow the disposal of liquid manure without causing odorous air pollution. Commercial firms are already aware of the potential market in odor-controlling chemicals and will be directing their resources toward the development of products that will bring about a satisfactory solution.

The immediate future also will be marked with changes in the layout and design of animal-production systems. Drainage will be routed away from feedlots and livestock enterprises. Runoff water falling on the feedlot will be intercepted. Space will be allocated for the location of detention basins and lagoons. Production systems will be placed away from creeks and streams. Wind-direction studies will dictate the construction site of livestock facilities in relation to the living quarters of neighbors, as well as those of the operator. A green-belt buffer zone will be used to surround livestock enterprises from invading subdivision development. Irrigation (or "manurigation") and other land-disposal systems will call for an area to be set aside for the purpose of accepting waste. Producers already in operation will be making studies to modernize or institute waste-disposal systems. In short, the problem has now come into focus. Action will be taken and will be based on the best available knowledge. Those who are working in waste management will be forced to glean the latest information and design data from the publications in an attempt to keep abreast of this rapidly changing field.

The foreseeable future, as used here, is that period when measures may be taken that are now possible but considered impractical. Perhaps they are considered impractical because they have not yet been forced into practice.

Animal nutritionists will give us a different ration because of the changes brought about in plant breeding. Improved protein and vitamin values of the grains we now feed will alter the composition of the ration and feed that animals receive. These diet changes will produce a different type of manure, which, from the large livestock operations, will support the purchase and operation of equipment that will transform this waste into a feed by-product. Nutrients, antibiotics, vitamin additives will be added before reuse.

In the foreseeable future, all animals may be raised in complete confinement. Modern technology has built the astrodome to isolate sports activities from the natural elements. It is now possible to build similar structures for animals to isolate them and their natural pollutants from adjoining areas. Such a structure increases labor efficiencies and allows for increased mechanization. The animals can now be provided with the optimum living environment. The air in the structure is filtered and treated to eliminate odors. The proper temperature and humidity are maintained to maximize the feed conversion. Such a structure would eliminate any problem of runoff.

These new animal production systems might be isolated by distance. Zoning regulations may exile them to a designated area of the state or county. A buffer zone of cropland several miles wide would separate these very large animal units from the urban society. Liquid manure, if not reused, could be applied to cropland in this buffer zone. When land is at a premium, the inexpensive desert regions of the Southwest may become the livestock center of the United States.

Technical advances in treatments systems will also be seen. The open lagoon may evolve into a closed, water-tight container from which no odors can escape. Gas would be collected and used as fuel to heat the contents, forcing the tank to become a digester. The development and utilization of cheap fuels will allow animal manures to be dehydrated and incinerated, in a manner that produces no air pollution and results in a minimal ash.

Despite all the advances in the area of meat, egg, and milk production, our society will continue to support research that seeks to find an alternative for these livestock products. Soybean meal and other protein sources can be processed to compete with that thick, tender steak of which we all dream. The success of these new products is, of course, contingent upon whether or not the residual chemicals, used in growing the soybean or other protein-producing crops, are present in small enough quantities to be acceptable to the human body.

The distant future can be projected with confidence. These predictions are either forgotten or surpassed by the time the distant future arrives.

It is not hard to imagine an animal (a hog, for example) eating a ration that eliminates body odors and repels insects at the same time. Further, that part of the ration passed as manure (assuming there still is some) has no objectionable odor, the odor is that of honeysuckle or some other highly acceptable scent. The animal is trained to deposit all waste in a hydraulic conveying system where it moves to a processing center. Here a centrifuge separates the liquid from the solids. The solids are sterilized and are shipped to grain consumers to be placed in fields (all urban lawns will be carpeted). The liquids go to the chemical factory to be processed into medicines, fertilizers, insecticides, and perfumes.

In the distant future, cells will be grown in cultures. Ham and steak cells will be divided and redivided and then fed in a solution in an antiseptic atmosphere. The feedlots will have given way to a series of giant vats. There will not be space on the world for the domestic animal. Nor will the world be able to afford the inefficiencies of reprocessing feed through animals. The geneticist will have bred a cereal grain that will contain all the nutrients and vitamins necessary for human life, including protein in a digestible form.

The truth of the matter is that the livestock industry and the general public cannot wait for the distant future. The immediate future begins now. The task is to start to work on today's problem with today's technology.

ADDITIONAL INFORMATION

Numerous conferences devoted entirely or in part to the presentation of research information on livestock-waste management have been conducted. Transactions from these conferences provide a valuable source of data for the person interested in pursuing animal-waste management in greater detail. A partial listing of these conferences and sponsoring organization is provided below.

1. National Symposium on Animal Waste Management, American Society of Agricultural Engineers, East Lansing, Michigan (1966).
2. National Symposium on Poultry Industry Waste Management, Poultry Science Association, Lincoln, Nebraska (1963).
3. Second National Symposium on Poultry Industry Waste Management, Poultry Science Association, Lincoln, Nebraska (1964).
4. Conference on Agricultural Waste Management, Cornell University, Ithaca, New York (1969).
5. Animal Waste Management Conference, Federal Water Pollution Control Administration, Kansas City, Missouri (1969).
6. Role of Agriculture in Clean Water, Iowa State University, Ames, Iowa (1969).

Research papers related to livestock-waste management are routinely published in several scientific journals. A listing of those most regularly publishing papers in this area are:

Agricultural Engineering
Agricultural Science Review
Applied Microbiology
Journal of Agricultural Science
Journal of Animal Science
Journal of Dairy Science
Journal of Soil and Water Conservation
Journal of the Water Pollution Federation
Poultry Science
Soil Conservation
Soil Science
Transactions of the American Society of Agricultural Engineers
Transactions of the American Society of Civil Engineers
Water Research
Water Resources

GLOSSARY OF TERMS

Activated sludge: A process of waste treatment used to biologically degrade organic matter in a dilute water suspension. Diffusion of air at a high rate through the liquor promotes the growth of bacterial and other organisms, which, acting on the organic matter in the presence of dissolved oxygen, produce a sludge floc.

Aeration: The bringing about of intimate contact between air and a liquid.

Aerobic bacteria: Bacteria requiring the presence of free (dissolved or molecular) oxygen for their metabolic processes. Oxygen in chemical combination will not support aerobic organisms.

Algae: Primitive plants, one or many-celled, usually aquatic and capable of synthesizing their food stuffs by photosynthesis.

Anaerobic bacteria: Bacteria not requiring the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered or completely blocked by the presence of dissolved oxygen and sometimes by the presence of highly oxidized substances, such as sodium nitrates, nitrites, and, perhaps, sulfates. Facultative anaerobes can be active in the presence of dissolved oxygen, but do not require it.

Anaerobic decomposition: Reduction of the net energy level and change in chemical composition of organic matter caused by microorganisms in an anaerobic environment.

Bacteria: Primitive plants, generally free of pigment, that reproduce by dividing in one, two, or three planes. They occur as single cells, chains, filaments, well-oriented groups, or amorphous masses. Most bacteria do not require light, but a limited number are photosynthetic and draw upon light for energy. Most bacteria are heterotrophic (utilize organic matter for energy and for growth materials), but a few are autotrophic and derive bodily needs from inorganic materials.

Biochemical Oxygen Demand (BOD): An indirect measure of the concentration of biologically degradable material (Food) present in organic wastes. It is the amount of free oxygen utilized by aerobic organisms when allowed to attack the organic matter in an aerobically maintained environment at a specific temperature (20 C) for a specific time (5 days). It is expressed in milligrams of oxygen utilized per liter of liquid waste volume (mg/l.) or in milligrams of oxygen per kilogram of solids present (mg/kg = ppm = parts per million parts).

Chemical Oxygen Demand (COD): An indirect measure of the biochemical load exerted on the oxygen assets of a body of water when organic wastes are introduced into the water. It is determined by the amount of potassium dichromate consumed in a boiling mixture of chromic and sulfuric acids. The amount of oxidizable organic matter is proportional to the potassium dichromate consumed. Where the wastes contain only readily available organic bacterial food and no toxic matter, the COD values can be correlated with BOD values obtained from the same wastes.

Digestion: Though aerobic digestion is being used, the term digestion commonly refers to the anaerobic breakdown of organic matter in water solution or suspension into simpler or more biologically stable compounds, or both. Organic matter may be decomposed to soluble organic acids or alcohols and subsequently converted to such gases as methane and carbon dioxide. Complete destruction of organic solid materials by bacterial action alone is never accomplished.

Dissolved oxygen (D.O.): The oxygen dissolved in sewage, water, or other liquid, usually expressed as milligrams per liter or as percentage of saturation.

Effluent: A liquid flowing from a containing space.

Facultative bacteria: Bacteria that can exist and reproduce under either aerobic or anaerobic conditions.

F/M: The ratio of organic food, BOD, to microorganisms.

Infiltration: The process whereby water enters the soil through the immediate surface.

Influent: A liquid flowing into a containing space.

Lagoon: An all-inclusive term commonly given to a water impoundment in which organic wastes are stored or stabilized, or both. Lagoons may be described by the predominant biological characteristics (aerobic, anaerobic, or facultative), by location (indoor, outdoor), by position in a series (primary, secondary, or other) and by the organic material accepted (sewage, sludge, manure, or other).

Manure: The fecal and urinary defecations of livestock and poultry. Manure may often contain some spilled feed, bedding, or litter.

Manure pit: A storage unit in which accumulations of manure are collected before subsequent handling or treatment, or both, and ultimate disposal. Water may be added in the pit to promote liquefaction.

pH: The symbol for the logarithm of the reciprocal of the hydrogen ion concentration, expressed in moles per liter of a solution, and used to indicate an acid or alkaline condition (pH indicates neutral; less than 7 is acid; greater than 7 is basic).

Pollution: The presence in a body of water (or soil or air) is degraded so that it impairs the water's usefulness or renders it offensive to the senses of sight, taste, or smell. Contamination may accompany pollution. In general, a public-health hazard is created, but, in some instances, only economy or aesthetics are involved as when waste salt brines contaminate surface waters or when foul odors pollute the air.

Population equivalent: The calculated human population that would normally contribute the same amount of BOD per day. A common base is 0.2 lb. (90.7 g) of 5-day BOD per capita daily. An animal unit producing 200 lb. (90.7 kg) of BOD per day will have a population equivalent (PE) of 1,000.

Seepage: The movement of water through the ground surface; influent seepage is movement of water from surface bodies of water into the soil; effluent seepage is discharge of water from the soil to surface bodies of water.

Settleable solids: Those suspended solids contained in sewage or waste water that will separate by settling when the carrier liquid is held quiescent for a specified time.

Sludge: The accumulated settled solids deposited from sewage or other wastes, raw or treated, in tanks or basins, and containing more or less water to form a semiliquid mass.

Suspended solids (SS): Solids that either float on the surface of, or are in suspension in, water, sewage or other liquid wastes and are largely removable by laboratory filtering.

Volatile solids (VS): That portion of the total solids residue driven off as volatile (combustible) gases at a specified temperature and time (usually 600 C for at least 1 hr).

Volatile suspended solids (VSS): That portion of the suspended solids residue driven off as volatile (combustible) gases at a specified temperature and time (usually 600 C for at least 1 hr).